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FINAL DEVELOPMENT REPORT

FOR A

DOPPLER-RANGE RATE CORRELATOR

THIS REPORT COVERS THE PERIOD 1 OCTOBER 1951
THROUGH 22 DECEMBER 1952

MELPAR, INC.
452 SWANN AVENUE
ALEXANDRIA, VIRGINIA

CONTRACT NO. Nonr-629-(00) OFFICE OF NAVAL RESEARCH 9 MARCH 1953

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ABSTRACT

This report covers the development of a device which exploits the correlation between doppler shift and target range rate as a means of improving the detection probability of existing echo-ranging sonar systems. A practical model of this device has been constructed, for evaluation purposes, which is suitable for installation aboard combat surface vessels as an adjunct to the QHB Sonar system. This device provides a visual display of target range rate and target range on a cathode ray tube whose intensity is controlled by the echo strength and the degree of correlation between doppler and range rate. This is accomplished by processing the returning signal with a group of narrow adjacent filter channels to divide the energy into channels according to the doppler shift, and by utilizing magnetic recording techniques to continuously store up to four previous ping returns. The displayed output is the result of envelope-integrating over five consecutive pings (the immediate return plus the four stored returns). The integration process exalts returns from targets whose range rate exactly corresponds to the doppler shift for five successive pings and suppresses returns which do not exhibit this correlation.

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LIST OF ILLUSTRATIONS (con't)

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PART I

SECTION A

PURPOSE

1. General.- The ultimate goal of the work covered by this report was the development of a device which would utilize the correlation between doppler shift and range rate to improve the detection probability of existing echo-ranging sonar systems. In accomplishing this purpose, the work fell logically into three phases:

a. A preliminary investigation to determine the possibility of exploiting the correlation between doppler-shift and range rate to improve recognition differential.

b. A design study to determine the methods and to develop the techniques necessary to accomplish the desired purpose.

c. The design and construction of an exemplary equipment, utilizing the techniques developed, which would be suitable for installation as an adjunct to echo-ranging equipment in combat ships.

SECTION B
GENERAL FACTUAL DATA

2. Identification of Technicians.- The work on this project was accomplished by the following persons:

a. NAME: Dr. Glen D. CAMP, Special Staff Assistant

EDUCATION: University of California -
B. S. (Chemistry) - 1927
M. A. (Physics) - 1934
Ph. D. (Physics) - 1935 (Thesis: "Non-Conservative Theories of Gravitation")

EXPERIENCE: 1942-1946
University of California - Division of War Research - Physicist. Underwater Acoustics, crystal transducers.

1946-1951
Staff Member of the Division of Industrial Cooperation of Massachusetts Institute of Technology; Assigned to the Operations Evaluation Group in the Office of the Chief of Naval Operations, Navy Department. Theoretical and experimental studies of naval operations to determine optimal tactics and strategies, primarily in the fields of pro- and anti-submarine warfare.

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EXPERIENCE - continued.

1951-Present
Melpar, Inc. - Consultant to the technical staff on a wide variety of problems including communication, detection, identification, fire control, etc.

UNCLASSIFIED PUBLICATIONS: Heavy Particle Interactions from Beta-Decay Theory Phys. Rev. 51, 1046 (June 1937)

Impedance Representation of Tangential Boundary Conditions Phys. Rev. 69, 501 (May 1946).

A Variational Method for Linear Dissipative Anisotropic Systems Phys. Rev. 69, 502 (May 1946)

SOCIETIES: American Physical Society (Fellow)
Washington Philosphical Society
Phi Beta Kappa
Tau Beta Pi
Sigma Xi, etc.

Total number of hours charged to project - 431.1

b. T. F. BURKE, Section Head

EDUCATION: B.S. in Physics - New York University - 1939
Indiana University - 1939-1942
Massachusetts Institute of Technology - 1946-1949
Major: Physics Minors: Math., Chem., Geology

EXPERIENCE: 1936-1939 - New York University - Cockcroft-Walton linear accelerator. Taught machine shop practice.

1939-1942 - Indiana University - Taught undergraduate general Physics. Design, construction, and operation of 45" cyclotron. High vacuum diffusion pumps.

1942-1946 - University of California, Division of War Research. Design of piezoelectric transducers, sonar, cavitation, ultrasonics.

1946-1949 - Massachusetts Institute of Technology (Acoustics Lab.). Taught Acoustics. Research in acoustics, elastic properties of rubber at high frequencies, cavitation. Planning, instrumentation, and execution of tests at sea for Navy project.

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1949-Present
Melpar, Inc. - Research work on filters, recorders, sonar, transducers.
Section Head in charge of sonar transducer project, beam forming devices, sonar trainers, voice channel compression equipment, and radar anti-clutter equipment.

SOCIETIES: American Physical Society
Sigma Xi

Total number of hours charged to project - 683.8

c. Hugh M. WILLIAMS, Project Engineer

EDUCATION: University of South Carolina - B.S. in E.E. - 1944

EXPERIENCE: 1945-1946
South Carolina Public Service Authority (hydro-electric plant) - Engineer engaged in turbine efficiency studies, water studies, and solution of general operating problems.

1946-1949
RCA, Victor Division - Engineer. Design and development work on special electronic equipment, component parts, facsimile equipment, tape and wire recording equipment, and broadcast audio equipment. Engineered construction of the prototype model of the Carrier Channel Terminal Equipment for Western Union Telegraph Co.

1949-Present
Melpar, Inc. - As Sr. Engineer, did development work on jobs involving Voice Channel Compression, and tape recording. As Project Engineer, has been in charge of development work on Voice Channel Compression System. Electromagnetic Delay Mechanisms, Sonar Transducer, Instantaneous Power Spectrum Displayer, and Multi-signal UHF Direction Finder. Presently Project Engineer in charge of development of the following projects: A Sonar System, an Electronic Correlation Device , Magnetic Recording Heads, A Beam Forming Commutator, and ASW Fire Control Equipment.

Total number of hours charged to project - 1140.6

d. Thomas E. BAYSTON, Senior Engineer

EDUCATION: University of Tennessee, Knoxville, Tennessee B.S.E.E. (Communications) - 1944

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EXPERIENCE: 1945-1946
U. S. Navy, Lt. j.g. - Sonar Field Engineer with Electronic Field Service Group. Installed, tested, calibrated, and maintained fleet sonar equipment. Trained ships maintenance personnel.

1946-1952
Naval Research Laboratory, Washington, D. C. - Electronic Scientist. Development of experimental sonar systems.

1952-Present
Melpar, Inc. - Engaged in work on doppler correlation techniques.

SOCIETIES: IRE (Associate)

Total number of hours charged to project - 1508.7

e. John Gordon MYERS, Senior Engineer

EDUCATION: B.S. in M.E. - Virginia Polytechnic Institute - 1927

EXPERIENCE: 1927-1933
Engineer on various bridge construction projects in the South and Northwest sections of the country. Resident engineer on two major bridge jobs in Arkansas, associated with Ira G. Hedrick, Consulting Engineer.

1933-1942
National Park Service. District Ranger, Wildlife Ranger, Natural History Photographer. Lectured and wrote on human interest angles of historical and natural history subjects. Lectured to travel groups, clubs and schools. Wrote for state conservation booklets and Sunday supplement sections of newspapers through Associated Press.

1942-1946
Seabees and Civil Engineer Corps of U.S. Naval Reserve with duty in Pacific Area and in Stateside training areas as technical instructor supervisor.

1946-1947
Field and Office Engineer for maritime construction company operating almost exclusively from floating equipment. Design and construction of materials handling systems on barges andof pier and dock substructures. Design of conveyor system for pulp and fertilizer docks and warehouses.

1947-1949
Field Engineer in shipyard constructing all welded tankers in 600 ft. plus class. Liaison between crafts and hull and machine design sections. Also maintenance of ways and yard. Design and construction of yard layout.

1949-1950
Structural Engineer and Assistant Superintendent on heavy construction work. Design and construction of sewage, waterworks, and wind tunnel structures. Operation and maintenance of heavy construction equipment.

1950-Present
Melpar, Inc. - Mechanical design on electromagnetic delay line circuit, sonar devices and circuit triggering devices. Packaging details of electromechanical devices.

Total number of hours charged to project - 1137.8

f. John W. GLOVER, Jr., Senior Engineer

EDUCATION: B.S. in E.E. - University of Maine - 1942

EXPERIENCE: 1942-1943
Naval Research Laboratory - System test of VHF search radar equipments. Development of high power VHF pulsed oscillators. Development of RF components for UHF Doppler Fire Control Radar System. Development of a method for carrier transmission of servo data for radar relay system.

1944-1945
Navy Department, Electronic Field Service Group. Technical Assistant to head of Radar Section.

1945-1947
Navy Department, Bureau of Ships. Project Engineer for airborne radio control and telemetering systems.

1947-Present
Melpar, Inc. - Development of 30-Channel Subminiature Microwave PPM Telemeter System. Development of miniature power transformers, a 30-phase transformer, magnetic amplifiers, and special purpose magnetic devices. Research on properties of new magnetic materials. Design of naval advanced base communication facilities. Development of a low frequency multicoupler.

Total number of hours charged to project - 169.2

g. John H. STEINBECK, Engineer

EDUCATION: Carnegie Institute of Technology - 1931-32 USDA Graduate School, 1947-1948

EXPERIENCE:

1930-1931
National Tube Co. - Asst. Chemist - Routine Chemical Analysis of steels.

1933-1935
National Tube Co. - Asst. Chemist - Analysis of steels, alloys, lubricants, etc.

1935-1936
Works Project Administration - Project Engineer - Preparation of work projects for local officials.

1940-1941
Army Ordnance - Asst. Inspector - Field inspector of ordnance material.

1941-1942
Balmar Corporation - Jig and Tool Inspector - Inspection of aircraft jigs and fixtures.

1942
Western Electric - Expediter - Field representative at plants holding sub-contracts for tools and fabricated products.

1946-1952
Naval Research Laboratory - Lab. Electronic Mech. - Construction, design and testing in laboratory and field of sonar units and assemblies, including propagation measurements, instrumentation, development and test of comb filters, display units and commutators.

1952-Present
Melpar, Inc. - Engineer - Design and test of electronic sub-assemblies and units associated with magnetic storage unit for use with a narrow-band analyser.

SOCIETIES: Washington Audio Society
Sigma Alpha Epsilon Fraternity

Total number of hours charged to project - 893.3

h. John J. BIRCH, Engineer

EDUCATION: Course in Physics - Harvard University - Summer 1949
Sc.B. in Physics - Brown University - 1950
Course in Transients and Linear Systems - University of Maryland (Bureau of Ships) 1951 - Present

EXPERIENCE: 1950-Present
Melpar, Inc. - Junior Engineer, Engineer. Transducer shell design; study of statistical problem of noise in radar systems; development and testing of magnetic heads and electromagnetic delay system. Presently engaged in design and construction work on a speech synthesizer.

SOCIETIES: American Institute of Physics
Philosophical Society of Washington

Total number of hours charged to project - 580.3

i. J. Brent FREY, Engineer

EDUCATION: Baltimore Polytechnic Institute - College Prep, Johns Hopkins University, Pennsylvania State College (Extension)

Class A. Licensee - Amateur Radio

EXPERIENCE: 1936-1937
B. & O. Railroad - Machinist Appr. Repair and maintenance locomotive driving mechanisms, and layout frames.

1937-1945
Bethlehem Steel Corp. - 8 years, including apprenticeship as roll turner. Turned and maintained rolls for slab, tin, pipe, wire and rod mills.

1945-1946
Gilt Edge Photo Service. Photo Finisher

1946-1951
Self-employed - Wholesale commercial photo finishing.

1950-1951
Bendix Radio, Baltimore - Test Department. Testing, alighment and trouble shooting of 108 to 135.9 megacycle omnidirectional aircraft navigation receivers.

1951-Present
Melpar, Inc. - CCA Trainer (Communications system) - Magnetic Mine Detector, Distributed Amplifiers, GRC-15.

SOCIETIES: ARRL

Total number of hours charged to project - 251.1

j. Thomas J. AMBROSE, Engineer

EDUCATION: B.S. in Physics - Union College - 1950

EXPERIENCE: 1942
Rome Air Depot - Junior Aircraft Electrician - Aircraft radio installation and maintenance.

1943-1945
U. S. Army - Radio operator and mechanic

1950-Present
Melpar, Inc. - Test engineering and redesign of telemetering subminiature equipment. Telemetering Engineer on Project Greenhouse.

Total number of hours charged to project - 45.0

k. Sol N. KOBLICK, Engineer

EDUCATION: (Post Graduate - 32 Credits), Polytechnic Institute of Brooklyn - 1951

EXPERIENCE: 1951
Polytechnic Institute - Research in X-ray intensities (Measurement of X-ray intensities by means of a Photomultiplier - Tubes 1P21, 1P28, 1P22, and 931A).

1951-Present
Melpar, Inc.- Review of Modulation Theory as applied to Telemetering. Investigation of theoretical and experimental aspects of Nonlinear Dielectrics.

SOCIETIES: American Physical Society
American Institute of Physics

Total number of hours charged to project - 40.0

3. Patents.

a. No patents now held by this contractor or under which he was licensed at the initiation of this contract are considered to be applicable to this problem.

b. No patents pending and no inventions being prepared for patent application as of the date of this contract are considered by the contractor to be applicable to this problem.

4. References.

a. "The Visual Presentation of Sonar Doppler Information," by J. V. Ellison, C. L. Dieter, and W. J. Finney - Report of NRL Progress, March 1951, p. 1 - CONFIDENTIAL.

b. "Magnetic Recording," by S. J. Begun

c. "Principles of Underwater Sound" - printed and distributed by the Research Analysis Group, Committee on Undersea Warfare, National Research Council.

d. "Physics of Sound in the Sea (Part I, II, III and IV)," Research Analysis Group, Committee on Undersea Warfare, National Research Council.

e. "Sound Recording," by V. G. Trayne and H. Wolfe.

SECTION C
DETAIL FACTUAL DATA

5. Background.

a. Ping-to-Ping Integration.- The range recorder conventionally used with echo-ranging equipments presents successive pings in close proximity. A human observer viewing this display can mentally integrate the returns from the last several pings. This integration process serves to emphasize targets which show an orderly trend (such as a submarine whose range changes relatively slowly and systematically) when compared with the erratic signals which compose much of the competing background. The improvement in echo/background ratio is evident after visual integration over only a few pings, and this effect contributes significantly to an operator's present target-detection ability.

b. Doppler Shift.- A sonar target need exhibit only a small radial component of velocity with respect to the reverberation background in order to produce a doppler shift which is audible against the reverberation. For example, in QHB the doppler shift is approximately 18 cycles per knot. Since it is probable that targets will be moving radially, such doppler recognition is usually an important factor in an operator's present target-detection ability.

c. Frequency Scan.- The equivalent filter bandwidth in which an operator can preferentially detect a doppler-shifted echo against a reverberation background is established by the attributes of human hearing, and is perhaps 50 cycles. The frequency Scan equipment developed at NRL is intended to improve on this performance by use of electric filters and by visual display of the result. In this system the filter bandwidth is made as narrow as is permitted by the sonar pulse length, and the rectified outputs of several such adjacent filters are displayed on an oscilloscope. The target need have only small velocity relative to the background in order to place the echo in a channel different from that containing most of the reverberation. Furthermore, the use of narrow filters improves the signal/noise ratio for any random noise which may be present. No provision is made for pulse-to-pulse integration except for a slight amount at short ranges, resulting from persistence of the scope phosphor.

d. Doppler Range Rate Correlator.- In present equipment, including the developmental Frequency Scan Indicator, no use is made of the correlation which exists between the range rate and the doppler shift. An operator may observe range rate by visual integration on the range recorder, and he may hear (or see) the doppler shift, but there is no mechanism to exploit the fact that these are related. Hence it is the basic purpose of this development to design an equipment in which this relationship is exploited to obtain improved detection.

Furthermore the developmental NRL equipment was designed for use with the LRS equipment whose long pulse length permits exceptionally narrow doppler filters and whose location aboard a submarine permitted certain simplifications. A subsidiary purpose in the present development is to construct a more versatile equipment suited to use aboard surface vessels with conventional sonar equipment (such as QHB).

6. Preliminary Investigation.

a. Purpose.- In order to establish the basic design parameters of this device, it was necessary to assess the value of the frequency scan technique and ping-to-ping integration, and to determine the probable value of a display which combines these effects to exploit the doppler-range rate correlation. Essentially, the purpose of this phase was to assimilate sufficient information to provide a basis for determining the optimum number of filter sections in the comb filter and the bandwidth of each, and the optimum number of pings to be integrated.

b. Selection of a Sonar System.- It was decided to design this equipment for use with the QHB Sonar system, because this is the most common sonar equipment in present use. In order to fully utilize a comb filter, the frequency stability of the sonar must be quite good. Due to the unicontrol system of frequency control used in QHB, the over-all stability can be made quite good by stabilizing the master oscillator. Although there is correlation between total doppler shift and range rate, there is no correla-

tion between target doppler[1] and range rate. Hence, the returning signal must be obtained from the QHB at a point ahead of the Beat Frequency Oscillator injection point in order to prevent the "own doppler nullifier" circuit from altering the doppler information. Also, the frequency of the signal at this point is more reliable than after being mixed with the BFO. Accordingly, it was decided to obtain the signal from the i-f section of the QHB audio receiver.

c. Filter width.- Work done at NRL on frequency scan displays indicates that the improvement in echo-to-background ratio in a visible display is proportional to the ratio of the over-all pass band of the receiver to the bandwidth of the individual filter which passes the echo. This is a significant improvement in most cases since the filter bandwidth can be made in the order of cycles whereas the pass band of the receiver is usually in the order of hundreds of cycles. A limit to the improvement that can be obtained by narrowing the bandwidth of each filter section is approached as the filter bandwidth approaches the inverse of the sonar pulse length. Since the QHB pulse length is in the order of 33 milliseconds the optimum filter bandwidth is approximately 33 cycles. Narrower filter bandwidths offer no appreciable gain since the echo energy begins to be distributed over more than one filter. However, it was deemed desirable to make the filter section bandwidths such that each filter channel would represent an integral increment of range rate as measured in knots. Since the doppler shift is slightly less than 0.7 cycles per knot per kc, the doppler shift for 1 knot range rate would be 18 cycles at the QHB operating frequency of 26 kc. Since 18 cycles is much too narrow for the QHB pulse length, a filter section bandwidth of 36 cycles, representing 2 knots range rate, was adopted. This bandwidth is near enough the optimum of 33 cycles, as determined by the QHB pulse length, to be satisfactory in both respects, i.e., optimum bandwidth and integral increment of range rate.

d. Number of Channels.- In order to minimize the complexity of this equipment, it was desirable to keep the number of range rate channels to a minimum. It was felt that some liberty could be exercised in this choice simply because this was a developmental equipment which could be modified as necessary after evaluation tests established the operating parameters needed. However, the choice was not entirely arbitrary. Since this equipment was to be primarily a detection device it was decided to include only closing range rates, it being improbable that an initial detection contact could be established on a target whose range was steadily increasing. Consequently 12 channels were selected as the number to be used, representing range rates from zero to 22 knots closing. The upper limit does not necessarily represent the optimum, but should be sufficient to permit successful evaluation tests.

e. Ping-To-Ping Integration.- Although it is difficult to assess the exact value of the ping-to-ping integration ability of the range recorder in terms of db improvement in signal-to-background level, it is possible to determine the value of its electrical analog. Successive ping returns can

[1]The frequency difference between the echo and the reverberations.

be added together electrically (with suitable methods of delay to obtain time coincidence) without regard to the phase relationships of the individual echoes if the ping return is rectified before adding and the voltage envelope used instead of the original signal. This is valid since the envelope accurately represents the instantaneous RMS amplitude of the return. Successive echoes then constitute periodic signals which when added together produce a result which is the sum of the individual echoes. Assuming n succesive echoes of equal intensity, the sum would be 20 log n db greater than any individual echo. Since the background noise, however, is a completely random process, its voltage envelope is also random in character, and successive background envelopes will add in power instead of in voltage. Thus n successive backgrounds of equal average intensity will produce a sum which is 10 log n greater than any individual background of the series. Thus, the improvement in signal-to-noise ratio resulting from adding n successive ping returns together is the signal increase minus the noise increase, 20 log n -10 log n, or simply 10 log n. This is the improvement, in db, of the signal-to-noise ratio after adding n ping returns. The addition of two ping returns gives a 3-db improvement, three pings gives 4.76 db, four pings gives approximately 6 db, and integration over five pings gives a 7-db improvement. After five pings, the improvement is less than 1 db per additional ping, and the number of pings stored and integrated over must be doubled to obtain another 3-db improvement. Although this is by no means an exact method of determining the improvement gained by the ping-to-ping integration ability of the range recorder, it is a useful estimate of that ability. Based on this estimate, five pings were selected as being the best number of pings to integrate over to obtain the maximum improvement without seriously violating the law of diminishing returns.

Since the number of pings stored and integrated affects the search rate of the sonar system, it was decided to include a switch to select a lesser number of pings to be stored and integrated in order to provide increased search rates when necessary. This actually is a variable that could best be resolved after evaluation tests at sea.

7. Design Study.

a. Approach.- The immediate objective of the design study phase of this project was to determine the best method of reducing the theory to practice. During this phase several methods of achieving the basic purpose in a practical equipment were given consideration before the approach actually used was adopted. Although the other approaches to the problem that were considered might possibly have resulted in a practical equipment, it is felt that the method finally chosen represents the best all-around approach in terms of available or standard techniques and technical "know how". In all of the methods considered the returning signal was to be processed by a group of filters to obtain the doppler shift information, and then processed or displayed in a manner to achieve the ping-to-ping integration that was desired. Since the filter operation was fairly straightforward, the major issue was the method of processing or displaying the signal to

obtain the ping-to-ping integration for exploitation of the doppler-range rate correlation.

b. Paper.- The first method that was investigated involved the use of a chemical paper recorder similar to the range recorder. The return, after being processed by the filters, was fed to a group of styli on the recorder, one stylus for each output of the filter, so that each stylus represented one doppler channel. Figure 1 shows the arrangement of this system. Sufficient space was provided between the styli to allow five pings to be recorded at normal paper speed without overlap. After five pings the paper was rapidly advanced by the amount of the window height to bring fresh paper under all of the styli preparatory to another run of five pings. In order to enable the operator to take maximum advantage of the ping-to-ping integration ability of the recorder, the starting, or zero, position of each of the styli was shifted during the five-ping run at a rate equal but opposite to the range rate represented by the doppler channel which fed the stylus. This caused all true targets, regardless of range rate, to appear as a vertical trace in the channel which represented their range rate. This is shown in figure 2. This relieved the operator's burden to some extent since he only had to watch for some semblance of a vertical trace.

Although this scheme had some minor drawbacks, such as the fairly large area which the operator was required to scan continuously, the major objection was the tremendous rate of paper consumption. An area the size of the window was used every five pings, and since this was basically a detection equipment, the display would be used almost continuously instead of just being used for actual tracking of a known target as the range recorder is used. The storage space required to provide enough paper to supply this device for only a few weeks at sea would be prohibitive.

c. Fading Paper.- In order to reduce paper consumption, effort was directed to finding some visible method of recording which would subsequently fade or which could be erased automatically in order to permit reuse. Such a recording material would permit the use of endless belts, and if the erasing time were reasonably short the belt lengths could easily be accommodated in the cabinet.

Upon study this turns out to be an unusually challenging problem when it is required that the means be suitable for service use. For example, it was deemed unsatisfactory to make use of tanks of liquid which might bleach the record. If gaseous erasers are to be considered, it is difficult to find bleaching gases whose leakage would be acceptable in the confined places aboard ship. The methods given at least cursory thought were extremely diverse (and perhaps amusing). For instance, it might be possible to deform visibly the nap of a velvet-like fabric by the motion of a stylus and then to erase this by raising the nap in an electrostatic field. Or perhaps to deform a pliable wax surface and then to restore it by remelting. Optical means were considered, in which a semi-permanent stress pattern in a transparent plastic might be made visible by Polaroid. All of these, and numerous others "work" but are impractical.

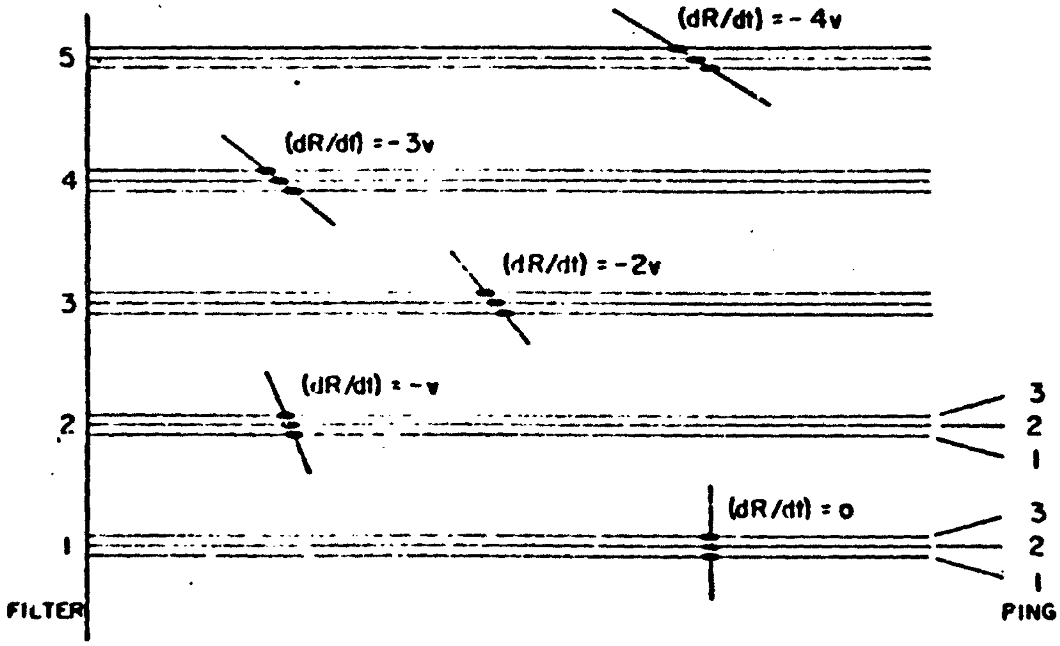


Figure 1. Range-Rate Doppler-Shift Correlation Display, DRRC

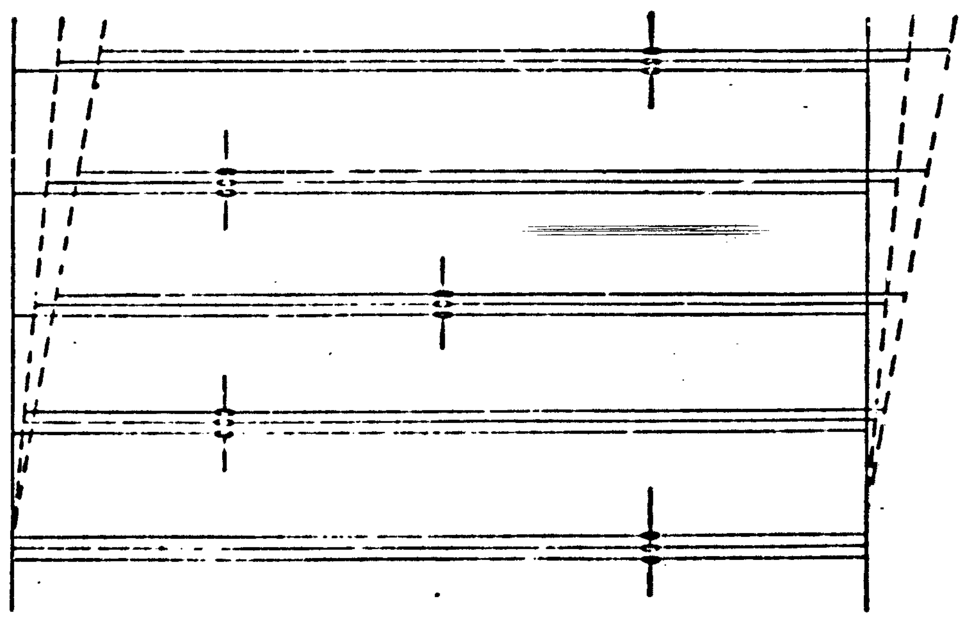


Figure 2. Range-Rate Doppler-Shift Display with Stylus Advanced, DRRC

The commonplace "Magic Slate" childrens' toy was investigated at some length. In this device a black wax-covered board is covered with a thin opalescent sheet of acetate plastic. Writing on the plastic with a stylus causes the point of contact to stick to the wax and to appear black. The board can be erased by lifting the acetate momentarily. This method works rather well and has a certain amount of dynamic range, principally by width modulation. However, the problem requires Z modulation over an appreciable dynamic range, and no materials could be found which appeared to hold much promise although all sorts (including friction tape, scotch tape, pitch, various waxes, etc.) were tried.

The method which looked most promising for a time involved the use of mercuric iodide (although it was realized that its permissibility was questionable). Mercuric iodide, normally a bright reddish-orange at room temperatures, abruptly changes color to a bright yellow at 127°C. This is a reversible physical change and does not involve any chemical change. Upon cooling the color slowly reverts to the original reddish orange. This material on an endless belt could be written upon by a hot stylus and would, during one revolution, return to its original state. Since there is no convenient way to heat and cool a stylus at the required 30-cycle rate, modulation would be obtained by varying the stylus pressure. Although several drawbacks were evident, such as limited dynamic range and some question of chemical stability, this method was under study until the following more practical method was evolved.

In considering gases which might be used in suitable chemical reactions to bleach a record, at least nitrogen, oxygen, carbon dioxide, and water are above suspicion and hence permissible. While others may exist, one involving carbon dioxide was finally hit upon and tested fairly thoroughly. The starting point is the fact that sodium carbonate and sodium bicarbonate, when electrolyzed, form sodium hydroxide at one electrode and carbon dioxide gas (plus water) at the other. The gas escapes but the sodium hydroxide does not. Since the hydroxide is a much stronger base than either carbonate, a suitable indicator could be used to turn color where the hydroxide was formed under the stylus. In the tests phenolphthalein was used as the indicator, giving a very bright reddish purple mark against a white background.

The erasure is automatic because sodium hydroxide absorbs carbon dioxide from the atmosphere fairly rapidly to form the carbonates. The carbon dioxide required for this is just that amount originally liberated at the other electrode, and so the entire cycle is reversible. In a closed system no carbon dioxide need be added; however, it would not be difficult to "charge" the atmosphere with sufficient carbon dioxide using a "Sparklets" cartridge or even the human breath.

After the basic principles were demonstrated it became evident that a slight modification was required. The tests used sodium bicarbonate, but this material converts to the full carbonate on prolonged exposure to the atmosphere, and the full carbonate is more basic than the bicarbonate. Whereas the pH of bicarbonate will not change phenolphthalein, that of the carbonate will, and so the paper gradually turned color on exposure to the air. There are two simple solutions to this difficulty: use a different indicator whose pH range

is higher (above 11), or buffer the pH down below the range of phenolphthalein. No indicator was found in this pH range which offered a color change as useful as that of phenolphthalein, and so a buffer was added. Nearly any buffer is admissible, provided its electrolysis products are acceptable. Sodium acetate was found to be satisfactory, and was added to the formulation. Hence, the paper treatment consists merely of a solution of sodium bicarbonate, sodium acetate, and phenolphthalein in water - an innocuous and inexpensive mixture, easily applied.

Of course this paper was still a "wet" paper, requiring the presence of a suitable amount of water to permit electrolysis. Several such papers (permanent marking) are well known, including that used in the present range recorder, and this paper would be no more difficult than they. However, the difficulty of retaining the proper moisture content is well known, and efforts were made to stabilize the water in this paper. These consisted of the addition of glycerine and some of its cousins, such as d-sorbitol, which act to retain water. The results were chemically interesting but disappointing, since the presence of these materials inhibited fading in the presence of carbon dioxide gas. It is supposed that the affinity of these compounds for OH ion is sufficient to "tie-up" the sodium hydroxide by olation and so prevent the reaction with carbon dioxide and yet leave the OH ion sufficiently free to change phenolphthalein. In any case no method of stabilizing the water in this paper was found.

The physical arrangement of a display using fading paper was visualized as a number of endless belts, one belt for each doppler channel. In order to avoid the mechanical problems of varying the starting positions of the styli, the same effect was achieved by tilting each belt of recording paper the proper amount with reference to the window (and direction of stylus travel). Although somewhat simpler mechanically this display was even more objectionable from the psycho-physical standpoint since the operator was required to visually scan a sizable area almost continuously. In addition to this, the display was still fundamentally a wet chemical paper recording process with all of its well known disadvantages. It was determined that an entirely fresh approach to the problem was necessary.

While these studies were in progress, attention turned to the magnetic recording method ultimately used, and no further work in the former direction was done. It is suggested that this fading paper may have other interesting applications, and that development should continue under separate contract.

d. Magnetic Storage.- This approach to the problem offered, by far, the most advantages of the various methods considered. Several variations of the basic idea were considered before the method actually used was finally adopted. In this method the sonar information is first processed by filters, as before, but the output of each filter is recorded on a rotating magnetic drum which has a separate track for each doppler channel. The diameter of the drum is sufficient to record four successive sonar pings.

Along each recording track are located four reproduce heads spaced approximately one sonar ping length apart, starting one sonar ping length after the record head. The exact spacing of the reproduce heads is such that four successive echoes, returning at a range rate corresponding to the doppler channel in which they occur will be reproduced by the four reproduce heads simultaneously with the occurence of the fifth consecutive echo. The amplified and rectified outputs of the four reproduce heads are linearly added with the rectified incoming signal to produce a signal voltage envelope which is the result of five-ping integration. There are as many integrated outputs to be displayed as doppler channels. These outputs are sampled by a commutator and displayed as Z axis modulation on a cathode ray tube. The cathode ray tube deflections are arranged to display range-rate (ordinate) versus range (abcissa) with the intensity being proportional to the echo strength and doppler-range rate correlation.

The magnetic storage method accomplishes the basic purpose of this project of simultaneously utilizing the two fundamental effects and exploiting the doppler-range rate correlation; however, the burden of integration in this scheme is shifted from the operator to the electronic circuitry. In addition, the display is compact and easy to observe, possesses good dynamic range, and is easy to interpret.

8. Development.

a. Purpose.- This phase of the project was concerned with developing the necessary techniques, methods, operating parameters, and component parts to enable a practical model equipment to be constructed. The effort during this phase was directed mainly toward the development of :

(1) a suitable magnetic recording storage method

(2) a sampling commutator

(3) filters

b. Magnetic Recording Medium.- The magnetic recording drum had to be capable of storing 12 individual tracks, corresponding to the 12 range rate channels as determined by the 12 filters. The circumference of the drum had to be large enough to store at least four successive pings during one revolution at a high enough rotational speed to give a linear surface speed sufficient to record the frequencies involved. The total frequency band stored on the drum is 432 cycles, 12 bands of 36 cycles each. Magnetic recording has a definite upper frequency limit which is proportional to the speed of the medium and inversly proportional to the magnetic gap of the reproduce unit. The rotational speed of the drum is fixed by the range interval and number of pings stored, and the gap width used represents a practical minimum. Thus, the frequency range had to be kept as low as possible in order to keep the required surface speed of the drum, and consequently its diameter, to a minimum. On the other hand, the frequency range had to be suitable for filtering with reasonable size inductors and capacitors

in the filter network.

Various types of magnetic recording mediums were considered for use as a drum surface. One of the first mediums considered was magnetic recording paper or acetate base tape, similar to that used in commercial tape recorders. Such tape has the best recording characteristics of any available medium, and sheets of this material are available. However, no successful method of attaching a sheet to the drum surface could be devised which did not have a discontinuity somewhere along the surface. Furthermore, the durability of tape under continued wear is questionable. Another medium considered was one layer of magnetic recording plated wire tightly wound on the drum to provide a recording surface. Experimentation with this technique, however, showed that the upper frequency response was inferior to that of tape, and the amount of flutter modulation was excessive. Both of these effects were undoubtedly due to the small area of contact between the magnetic head and the rounded surface of the individual wires, and to the slight differences in diameter of various individual turns which caused this contact area to vary appreciably.

The medium finally used was magnetic recording rubber bands made by Brush Development Co. These bands are made of neoprene rubber impregnated with red iron oxide powder to make them magnetic. The rubber is also impregnated with a wax to continuously lubricate the surface to reduce the friction between the rubber and magnetic heads. The recording response of a sample band on an experimental drum is shown in figure 3 for a surface speed of approximately 1.5 inches per second. The frequency response compares favorably with acetate base tape, the output being only slightly below that of tape. Based on this frequency response, the frequency band was set at 180 cycles to 612 cycles. This band was also suitable for filtering.

c. Recording Drum.- In order to determine the proper rotational speed of the drum to store four pings, the speed of sound in water was assumed to be 4920 feet per second. This was based on the following assumptions:

Average depth = 50 feet
Salinity: 34 parts per thousand
Nominal temperature: 57.2°F

The error due to temperature will be +2½% at 40° F and -2½% at 81° F.
The time required for a ping at 3750 yard range is:

$$\frac{3750 \times 2 \times 3}{4920} = 4.57 \text{ seconds.}$$

Keying at an interval of 4.7 seconds allows 130 milliseconds for equipment recovery time since:

$$4.7 - 4.57 = 0.13 \text{ seconds.}$$

By increasing the speed of the drum exactly 2½ times for the 1500 yard range interval, the time allowed for a ping is:

$$\frac{4.7}{2.5} = 1.88 \text{ seconds.}$$

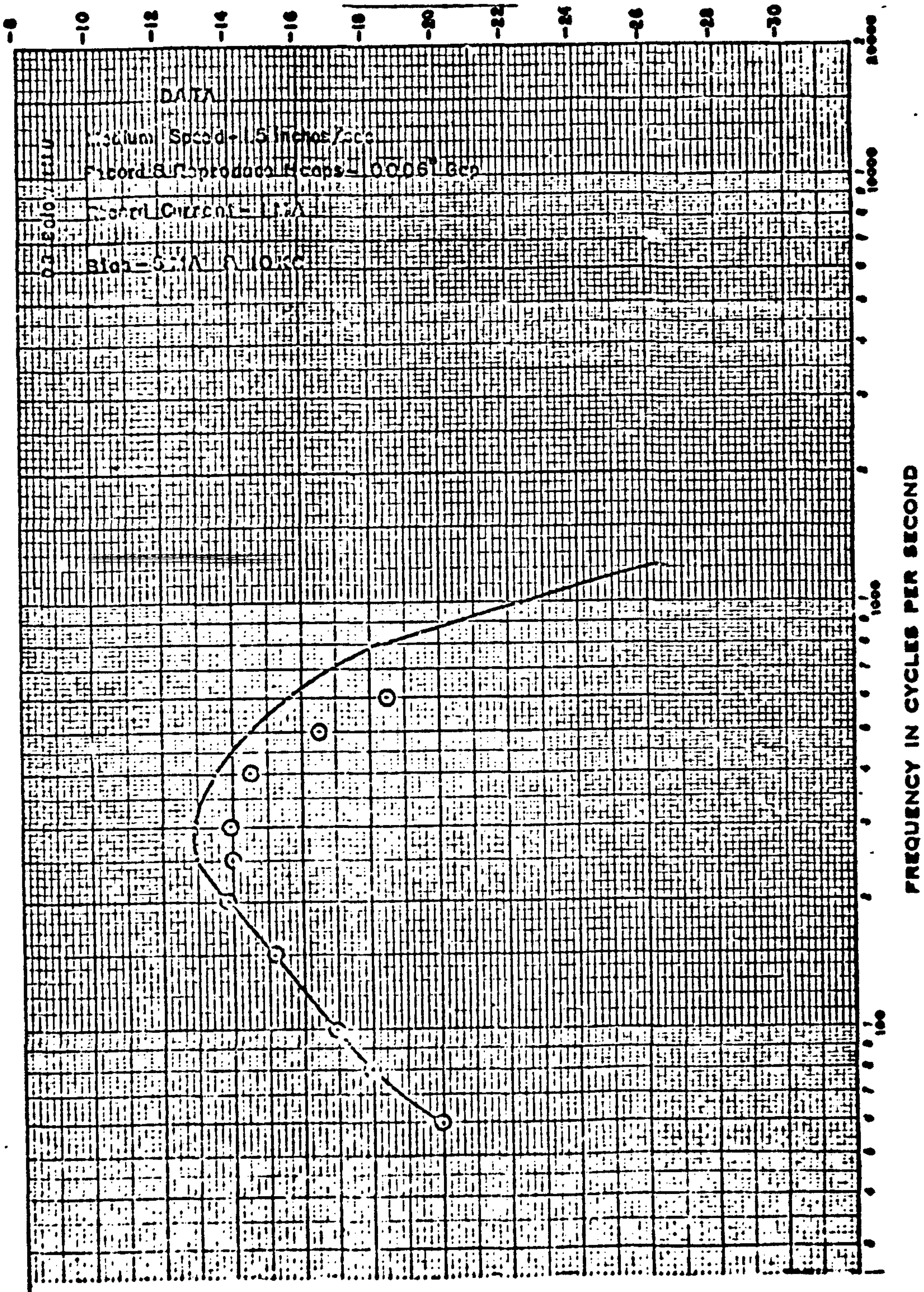


Figure 3. Frequency Response of Sample Band of Magnetic Recording Rubber on Drum, DERC

The time required for one ping at the 1500 yard range interval is:

$$\frac{1500 \times 2 \times 3}{4920} = 1.825 \text{ seconds.}$$

Thus, the time allowed for equipment recovery for the 1500 yard range interval is 55 milliseconds since:

$$1.88 - 1.825 = 0.055 \text{ seconds.}$$

The drum is divided into five equal areas, four for storage and one for erase, and rotates at 2.553 rpm for the 3750 yard range rate to give exactly the 4.7 seconds time required to rotate 1/5 of a revolution. A cam geared to the drum operates the keying microswitch once each 1/5 of a revolution to give five pings per drum revolution. The synchronous motor drives the drum through two speed reducing gear trains which incorporate electromagnetis clutches, one for 3750 yards and the other for 1500 yards. The proper gear train is selected by the operation of the proper electromagnetic clutch. The over-all diameter of the drum with the rubber in place is 12.7 inches giving a surface speed of approximately 1.7 inches per second at the 3750 yard range rate.

d. Magnetic Record-Reproduce Units.- The record-reproduce heads used in this equipment are a modified version of a design developed earlier. A certain amount of experimentation was necessary to determine the optimum gap size to use in this application, and considerable effort was devoted toward improving the quality control in manufacture to assure a uniform product. The completed head is potted in plastic in a soft iron cup which acts as a magnetic shield. Figure 4 shows the component parts of one of the heads in an exploded view, a completed head, and a cross sectional view of a completed head. The magnetic pole pieces of the heads are made of 0.006" moly permalloy laminations which are hydrogen annealed after stamping. The pole piece faces are first ground and then sent through several lapping operations to assure uniform flat surfaces. The gap is made of 0.0006 inch aluminum foil. The coil is wound on a nylon bobbin, and a nylon insert is used to position the head in the cup. The entire unit is encapsulated in a Bakelite potting compound. The characteristics of these heads are as follows:

Gap width: 0.0006 inch
Inductance: 80 mh, record unit
100 mh, reproduce units
Freq. response: uniform to about 100 kc

e. Sampling Commutator.- The sampling commutator is required to sample sequentially the outputs of the 12 channels in order to display the information on a single cathode ray tube. Since the highest frequency components contained in the rectified envelope of the 33-millisecond QHB pulse are in the order of 33 cycles, the sampling rate must be at least 66 samples per second (twice the highest frequency component in the information sampled).

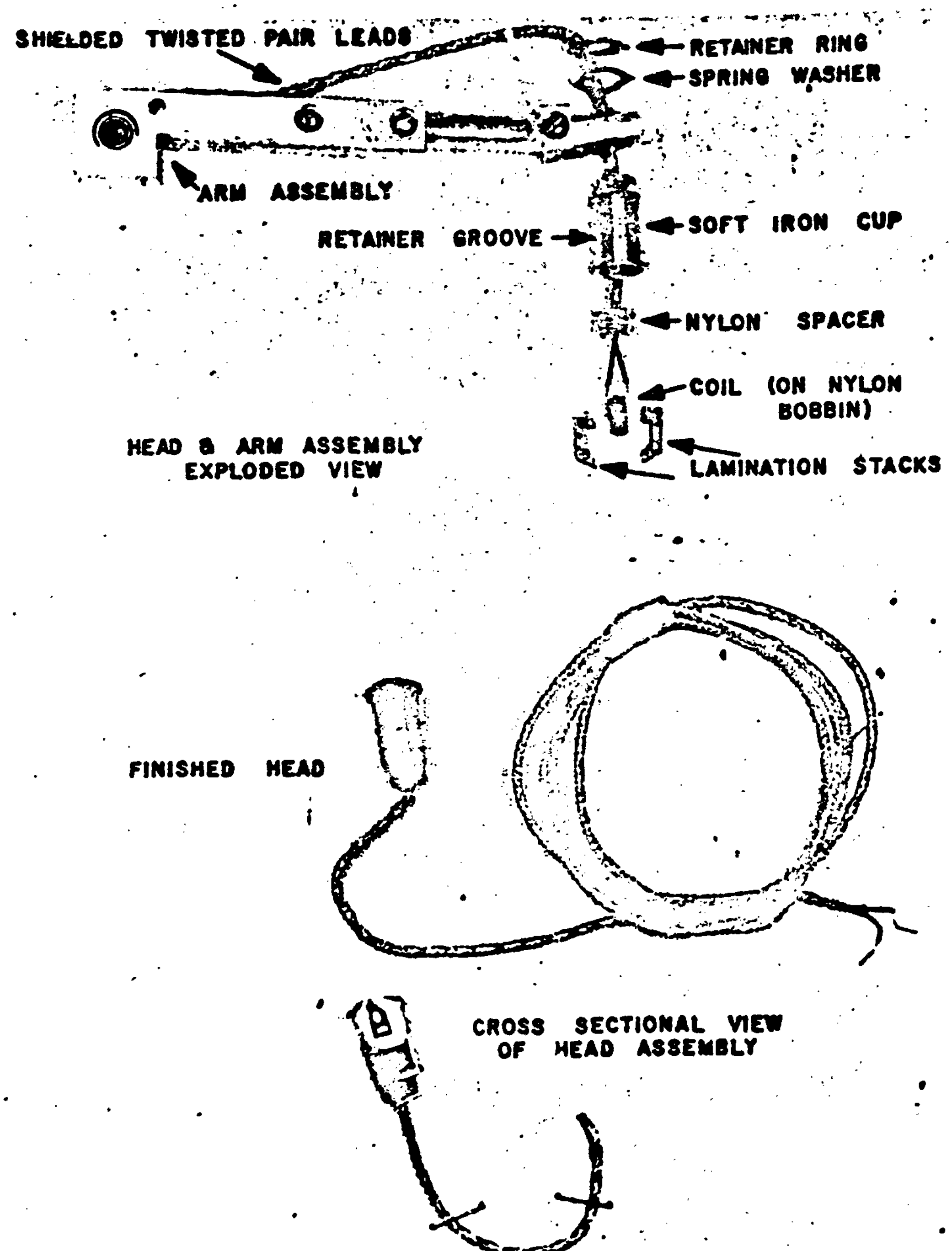


Figure 4. Exploded View, Assembled View and Cross-Sectional View Of Completed Record-Reproduce Head, DRRC

In order to assure good sampling, a sampling rate of 100 samples per second was chosen. An electronic sampling switch can achieve this sampling rate with comparative ease, but in order to keep the size, complexity, and electronics at a minimum, it was decided that a simple motor-driven mechanical commutator would be the most desirable. Commercially available signal sampling commutators, designed for telemetering applications, sample at rates much slower than 100 samples per second with rather short life expectancies. However, after considerable experimentation with various contact materials, a successful commutator was developed which sampled at the desired rate and showed no measurable wear after several hundred hours of operation.

The final commutator design employs silver graphalloy brushes running on coin silver commutator segments. Silver graphalloy, a commercially available compound of silver and graphite, was finally chosen as a brush material for its self lubricating properties which reduces the brush wear to a minimum. The commutator segments are made of coin silver bonded to a copper base. This material was used rather than silver plating the segments since the coin silver is much harder than plated silver.

During the development of this commutator it was found that a relatively soft brush running on relatively hard commutator material gave the best results. Brushes made of material as hard as or harder than the commutator segments, such as tungsten or silver alloys, would start to gall at the slightest imperfection in the commutator finish and would wear the commutator enough to render it useless in a short time.

The commutator segements are held in place by potting in a thermosetting resin compound. The commutator was made of 24 segments, opposing segments being connected in parallel, so that the information was sampled twice for each rotation of the brush. Thus, the commutator gives a sampling rate of 100 samples per second when driven at 3000 rpm. An induction motor running at this speed supplies the drive. The commutator is arranged for non-shorting operation with each information channel contacted about 75% of the total available time, the remaining 25% dead time being used for contact transfer.

f. Filters.- Design of the filters was relatively straightforward. For these frequencies, conventional lumped constant, L C filter design was adequate. The final design employs constant K type single T section filters. Powdered iron toroidal cores were used in the inductances. The full T section, which was required to obtain the desired steepness of the filter characteristic slopes, yields an adjacent band rejection of at least 12 db. The constant K type T section was also the most suitable design for this application since it was most convenient to drive all filters in parallel from a common source. Since the impedance of the constant K T rises outside of the pass band, mismatch due to the filters loading one another is minimized. Figure 5 shows the response curves of the individual filters, independently driven, and figure 6 shows the response of the filters when driven in parallel from a common source in a circuit identical to that used in the equipment. Figure 7 shows the voltage variation at the input of a typical filter unit as the

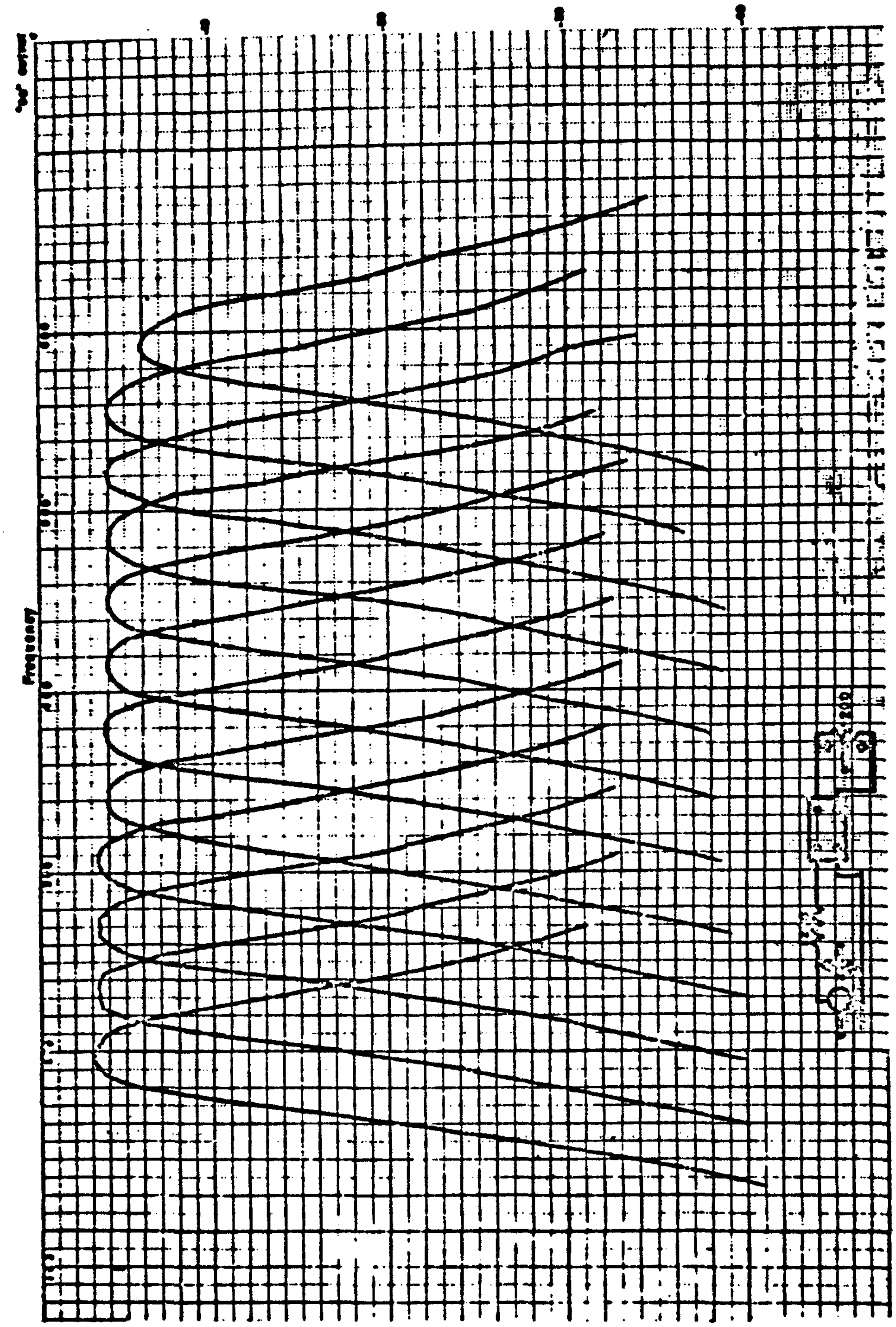


Figure 5. Response of Filters, Independently Driven, DRRC

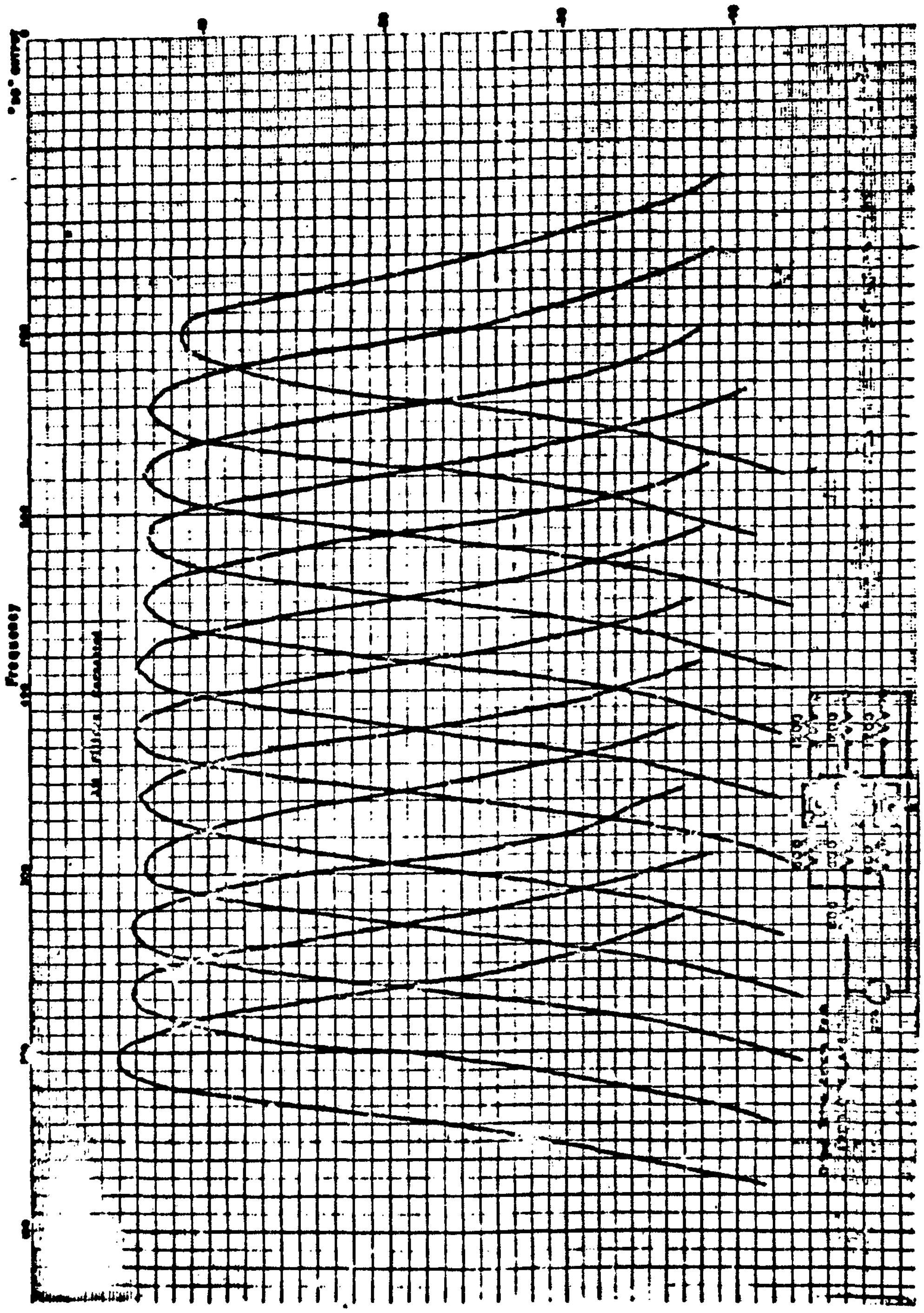


Figure 6. Response of Filters, Driven from Common Source, DRRC

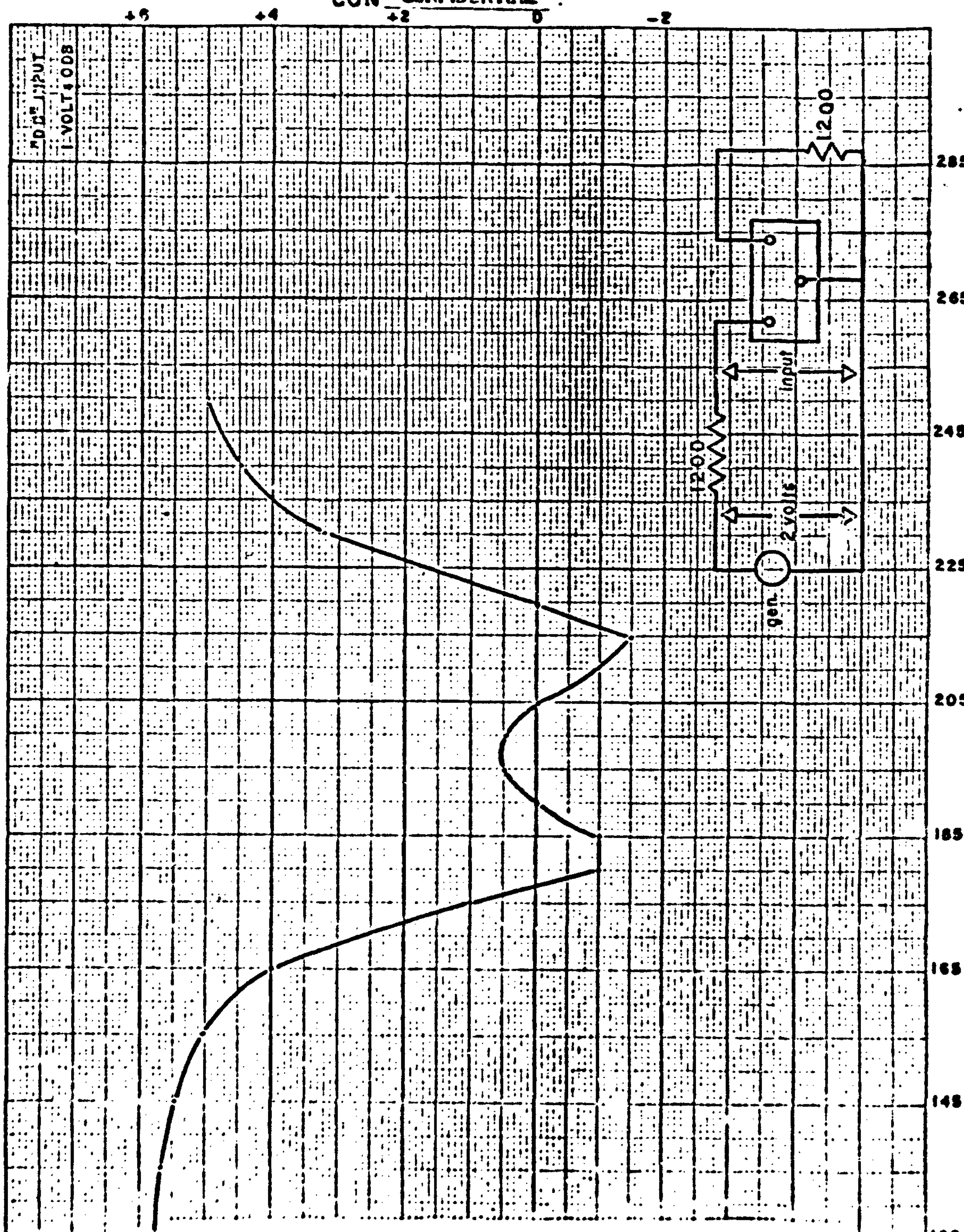


Figure 7. Typical Filter Input Characteristic, Input to Filter vs Frequency, [illegible]

frequency is varied through the pass band of the filter. The filter loads the driving circuit very little outside of its pass band.

9. Equipment Description.

a. Data.

(1) Cabinet Size: 19½" wide x 22½" deep x 41" high, over-all, including desk and bulkhead shock mounts and clearance for control knobs. Figure 8 shows outline and mounting dimensions.

(2) Weight: 320 lbs. including shock mounts.

(3) Finish: Exterior, gray enamel; interior, aluminum is iridited and water lacquer finished, ferrous metals cadmium plated and/or gray enamel.

(4) Power Requirements: 480 volt-amperes at 115 volts, 60 cycles.

(5) Interconnection: A diagram showing the interconnection wiring between the DRRC and QHB is shown in Figure 9.

b. Cabinet.- Figures 10 and 11 are front and rear views of the cabinet showing the location of the various chassis and controls. The frame is made of 3/4" x 3/4" x 1/8" cold rolled steel angle and is of all welded construction. Frame covers of 1/16" cold rolled steel sheet are used to help shield the magnetic storage unit from stray magnetic fields.

c. Power Supply.- Two views of the power supply are shown in figures 12 and 13. The power supply is constructed on a 1/16" cold rolled steel cadmium plated chassis, and the cover is of 1/32" cold rolled steel, also cadmium plated. All transformers are hermetically sealed in steel cases.

d. Display Chassis.- Figures 14 through 18 show the display chassis. It is constructed basically of aluminum, with the cathode ray tube shield, commutator shield, and miscellaneous small parts of steel or steel alloys. Various views of the individual component chassis are shown in figures 19 through 24, and figures 25 through 27 show the sampling commutator.

e. Filter and Reproduce Amplifier Chassis.- This chassis contains the 12 band pass filters and the 12 plug-in amplifier units which contain the 48 reproduce amplifiers, four amplifiers per unit. Figures 28 through 30 show the chassis, figure 31 shows the channel on which the 12 filters are mounted, figure 32 shows the RC parallel T rejection filters, and figures 33 through 35 show various views of one of the plug-in amplifier units.

f. Magnetic Storage Chassis.- The magnetic storage chassis contains the magnetic recording drum, associated drive motor and gear train, the 12 magnetic record units, one per range-rate channel, and the 48 magnetic reproduce units, four per channel, distributed around the periphery of the drum.

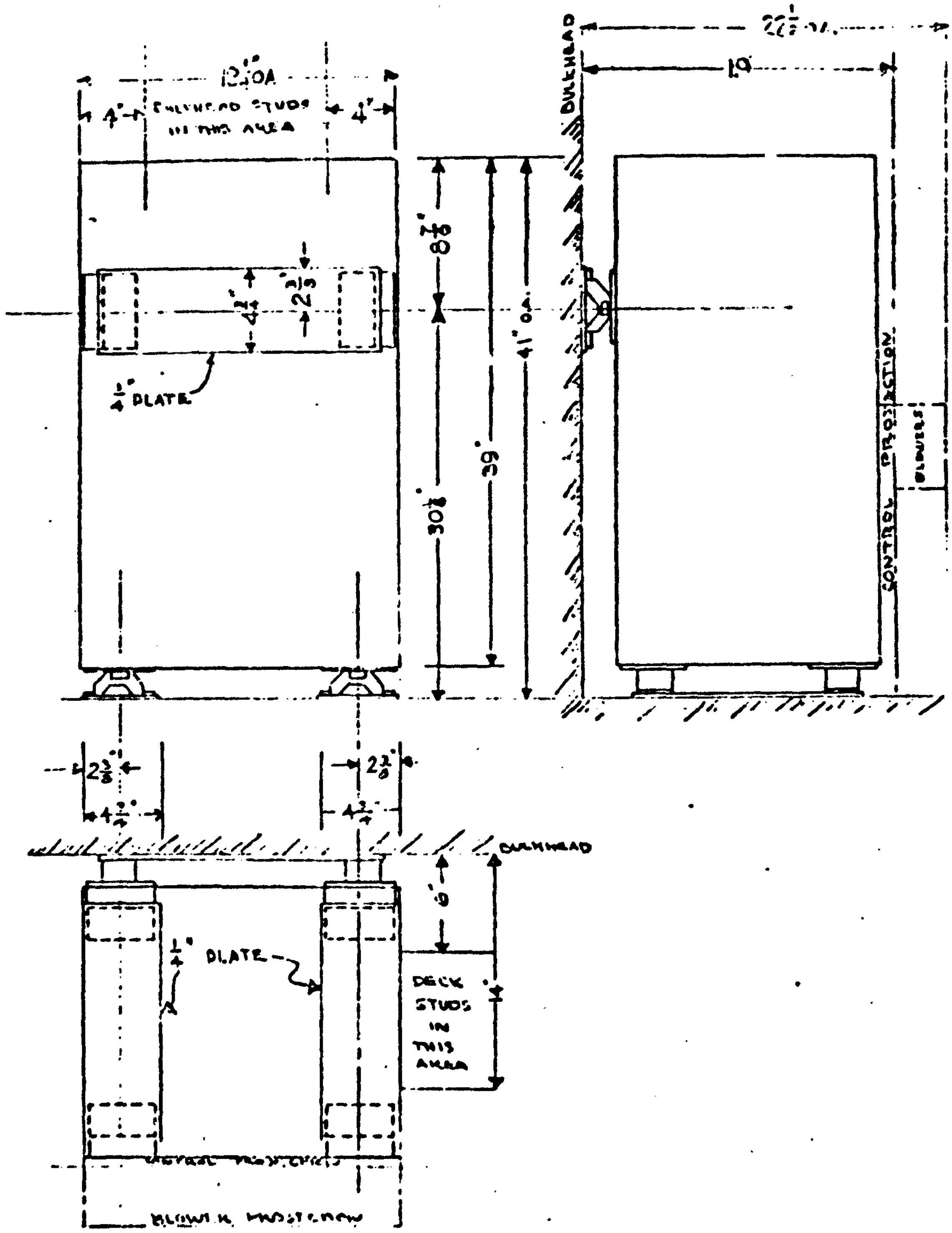


Figure 8. Outline and Mounting Dimensions, DRRC Equipment

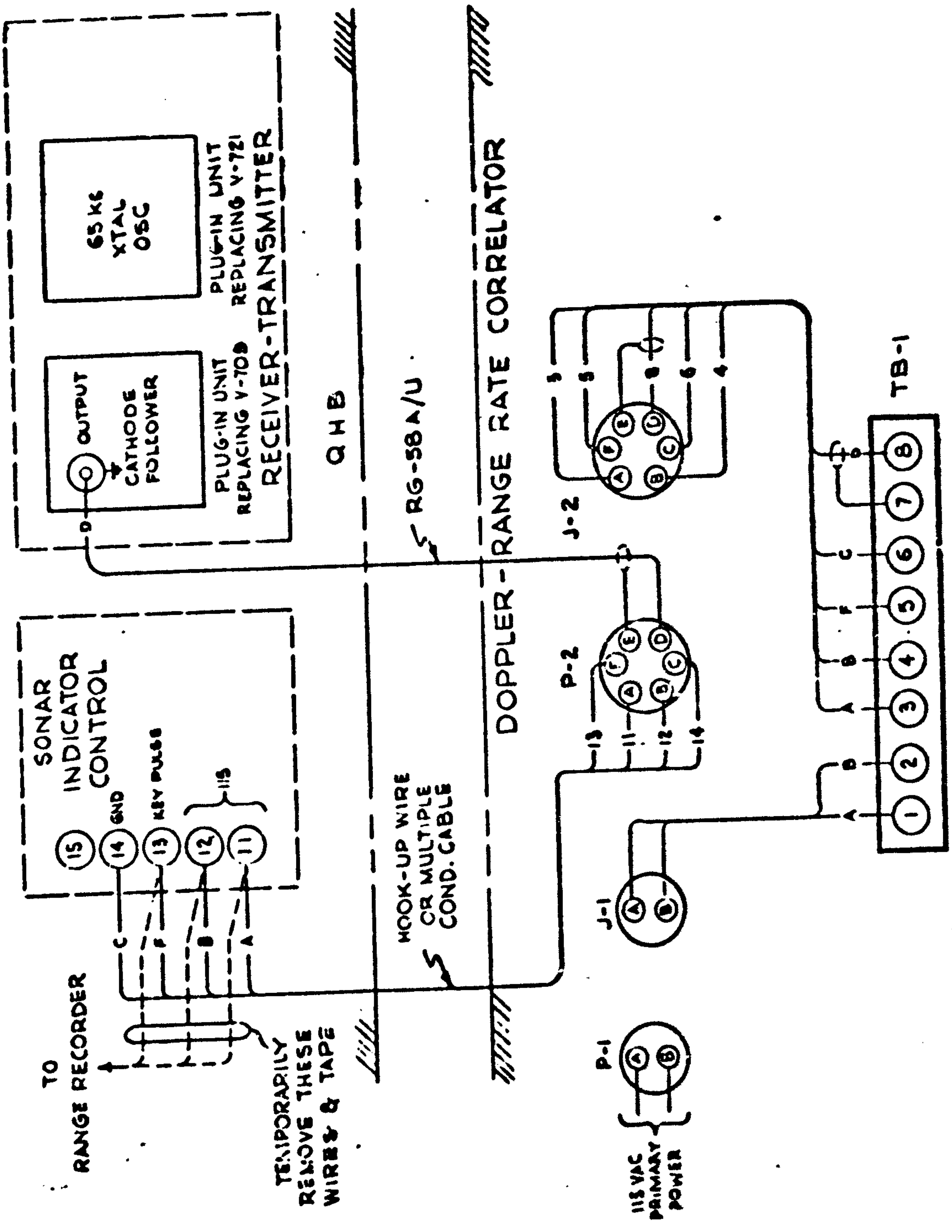


Figure 9. Interconnection Wiring between DRRC and QHB

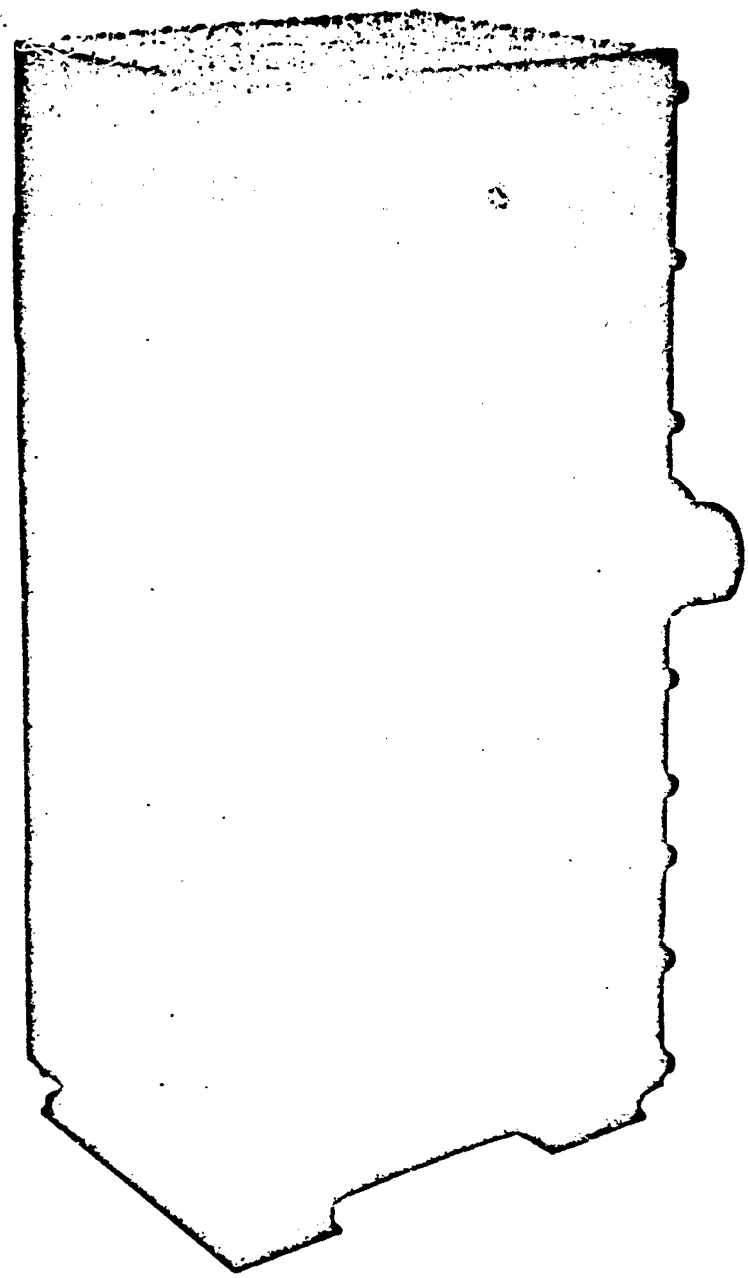


Figure 10. DRRC Equipment, Front Three-Quarter View

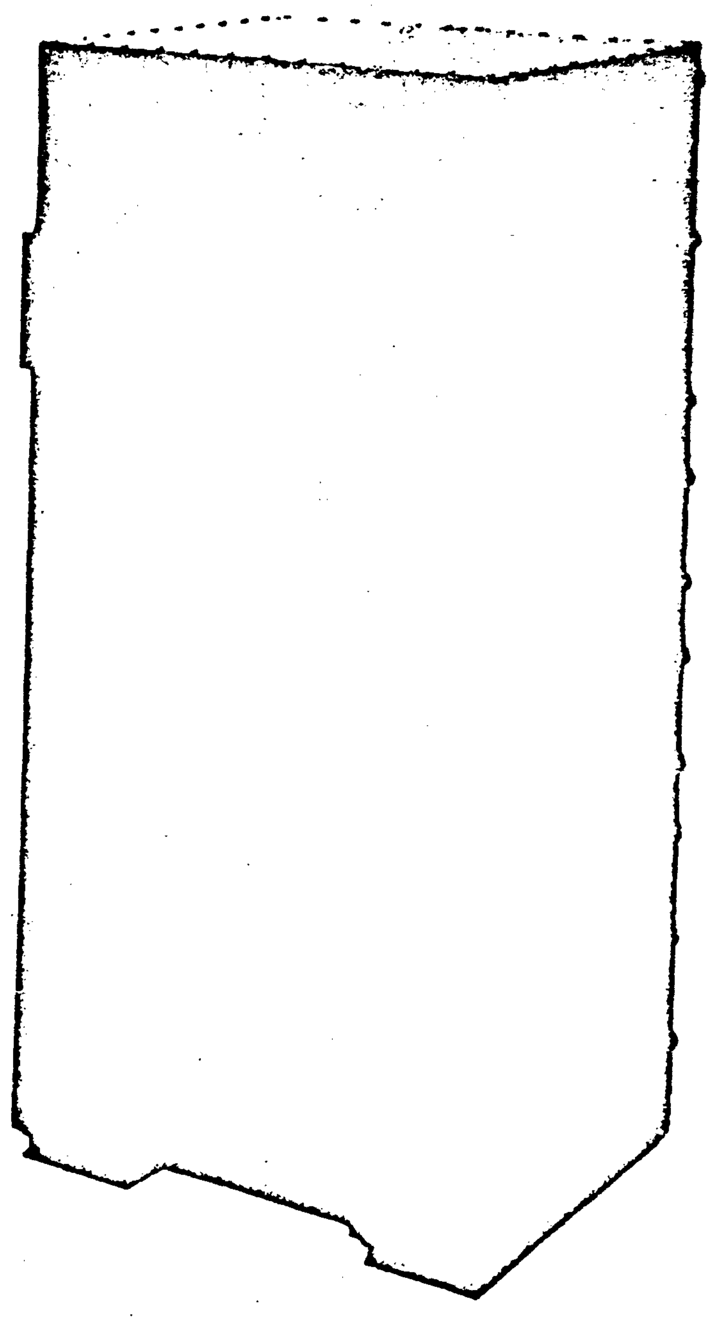


Figure 11. DRRC Equipment Rear Three-Quarter View

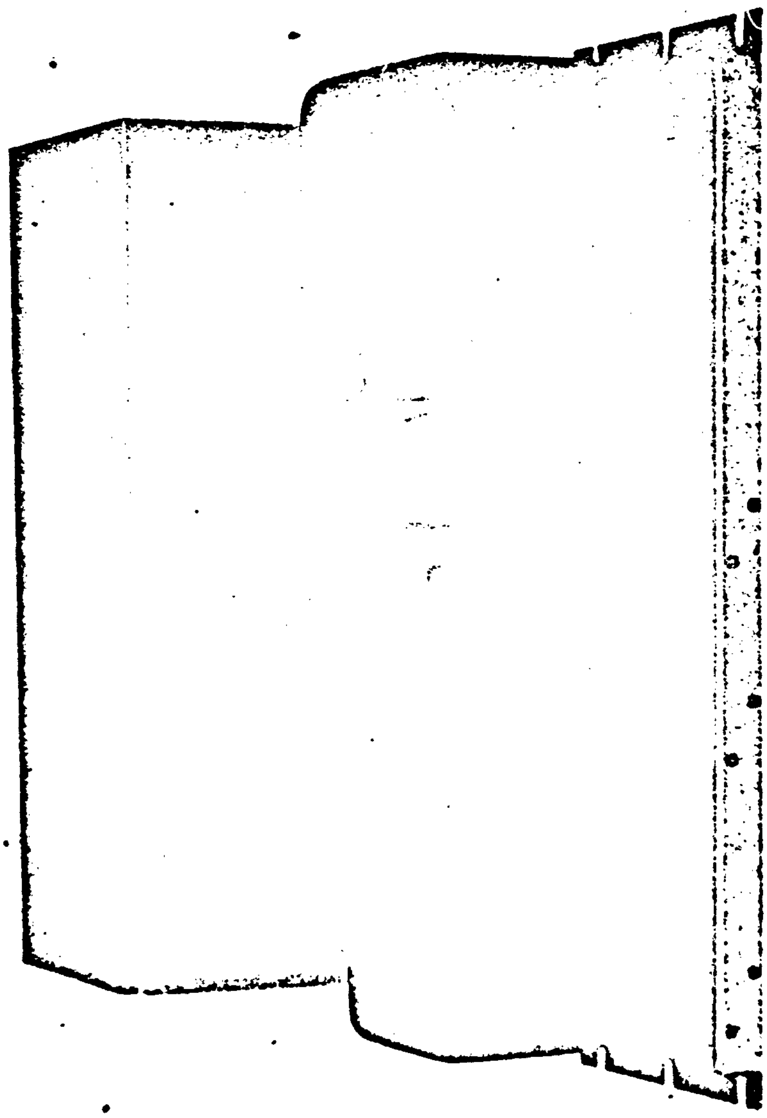


Figure 12. DRRC Power Supply, Top Three-Quarter View

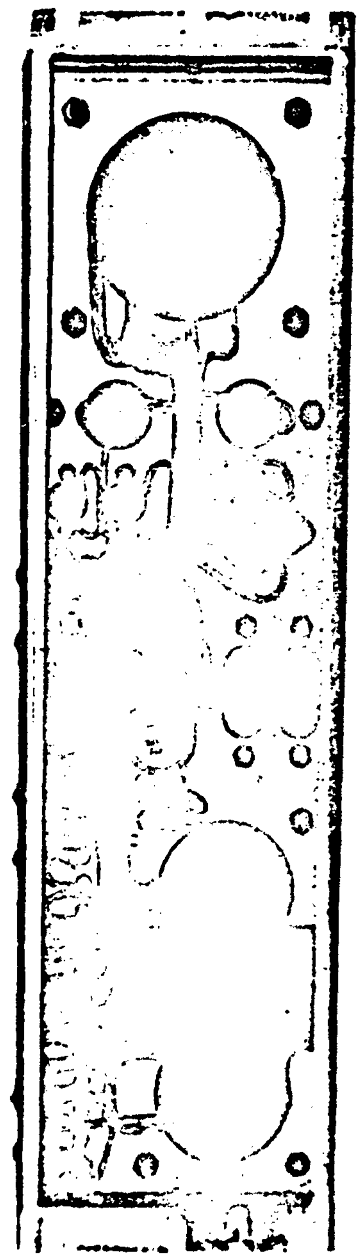


Figure 13. DRRC Power Supply, Bottom View

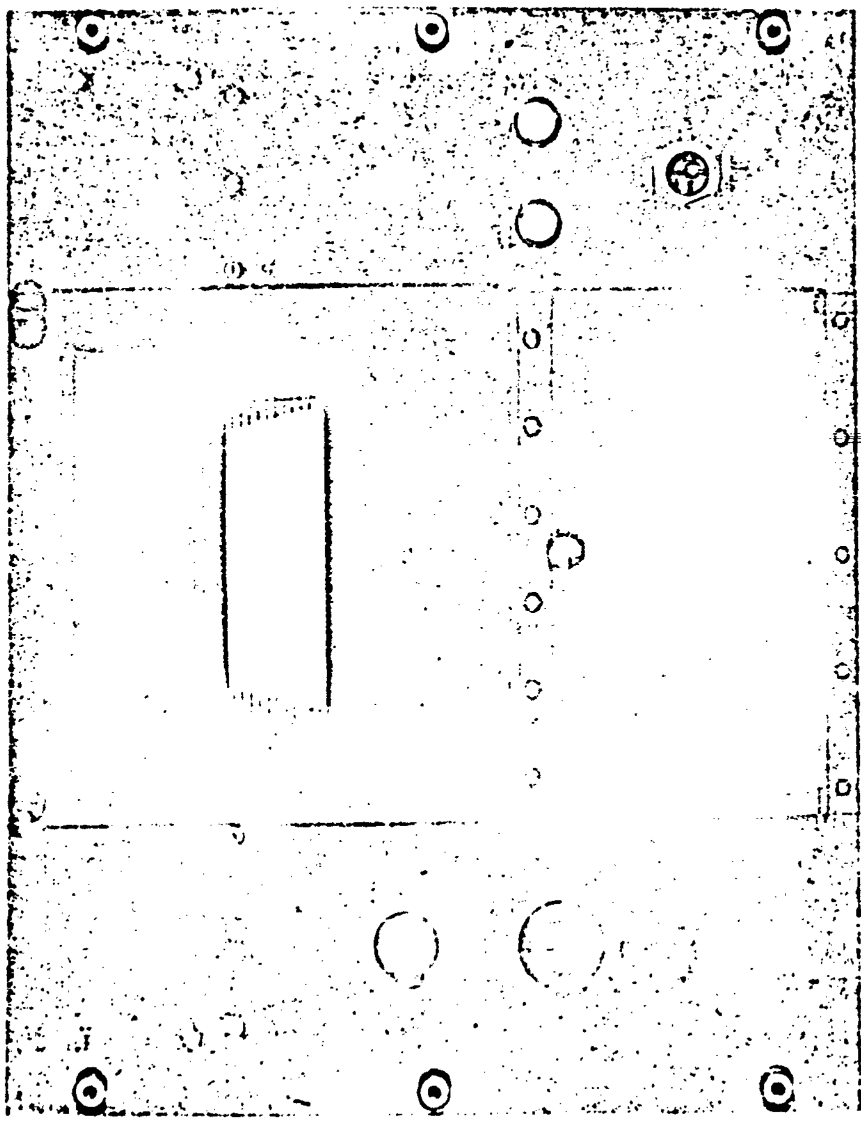


Figure 14. DRRC Display Chassis, Front View

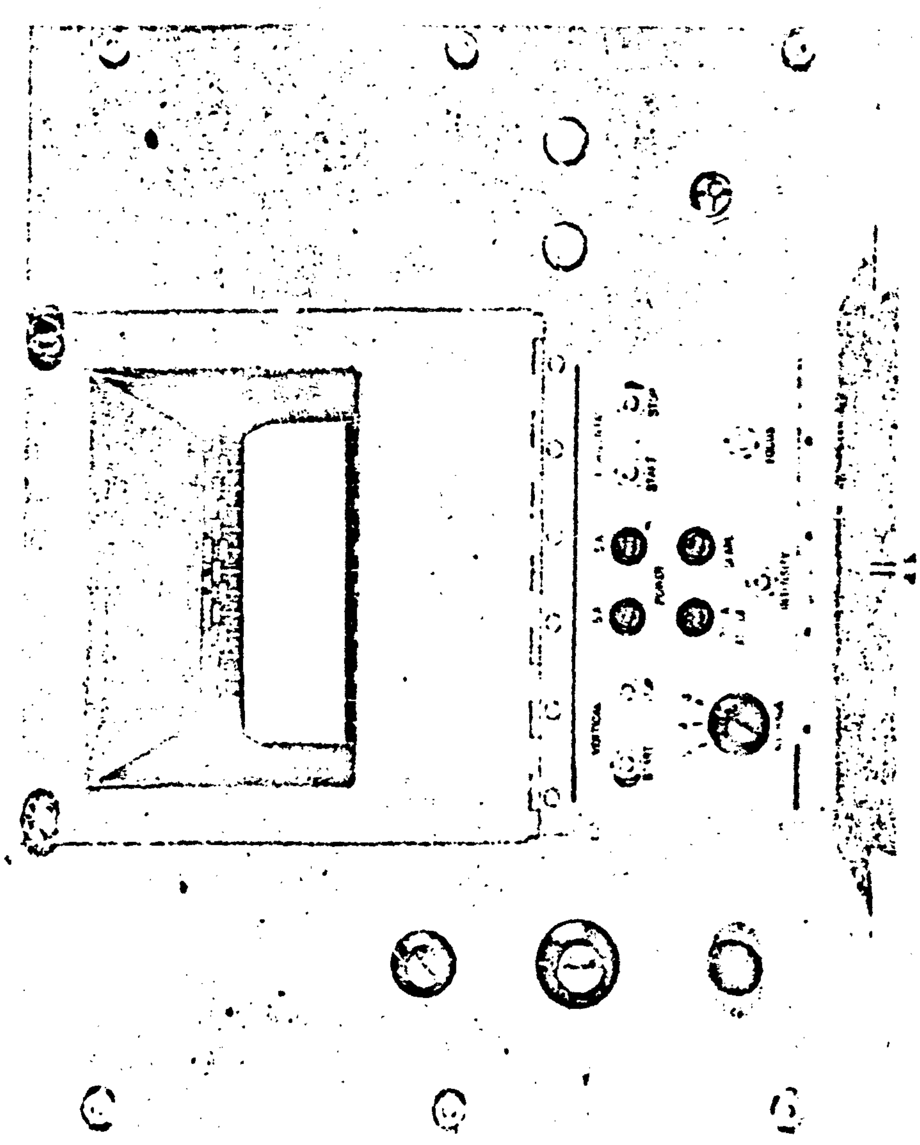


Figure 15. DRRC Display Chassis, Front View, With Access Door Open Showing Scope Controls

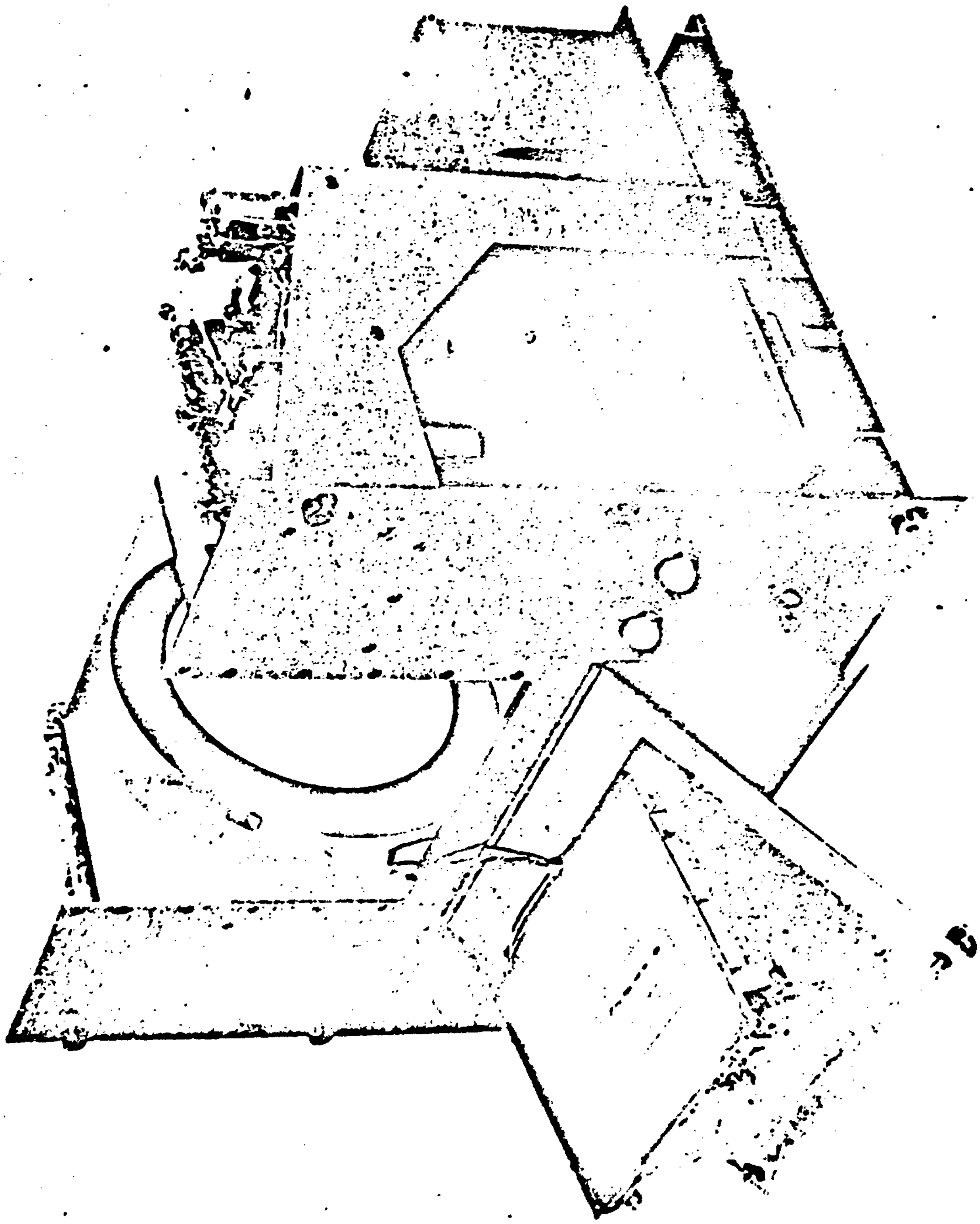


Figure 16. DRRC Display Chassis, Showing Hinged Panel Open for CRT Removal

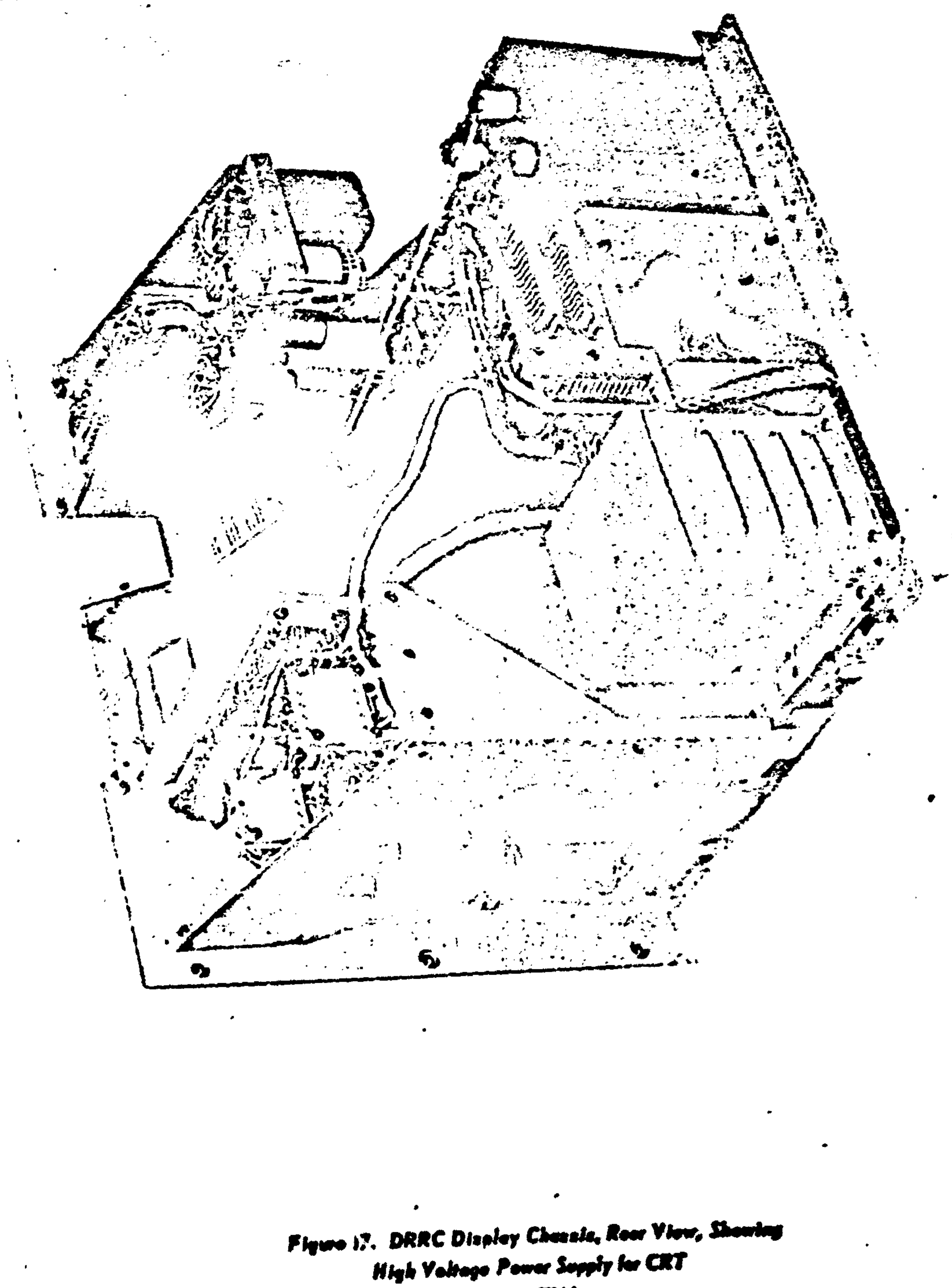


Figure 17. DRRC Display Chassis, Rear View, Showing High Voltage Power Supply for CRT

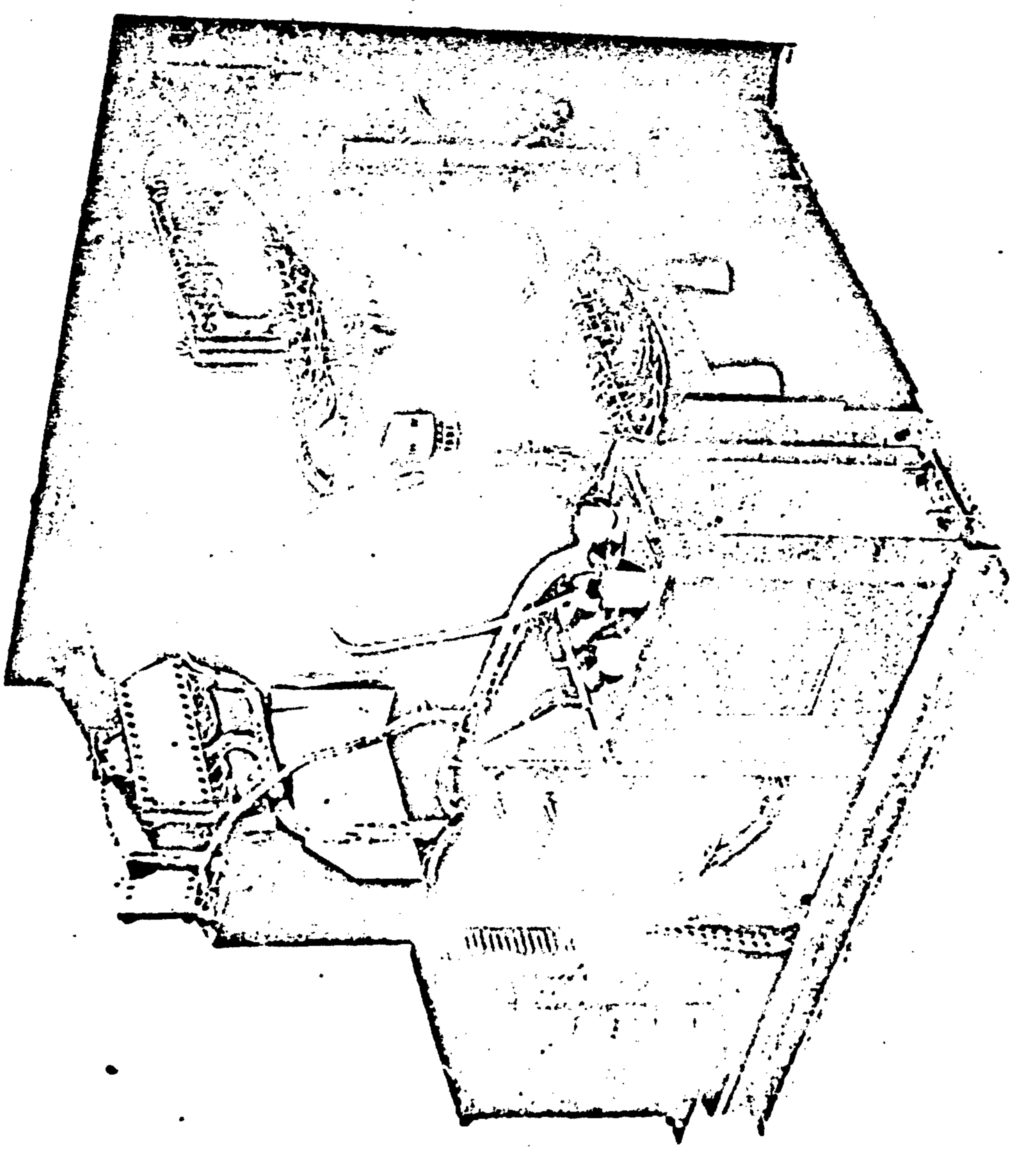


Figure 18. BRRC Display Chassis, Rear View, Showing Commutator Location

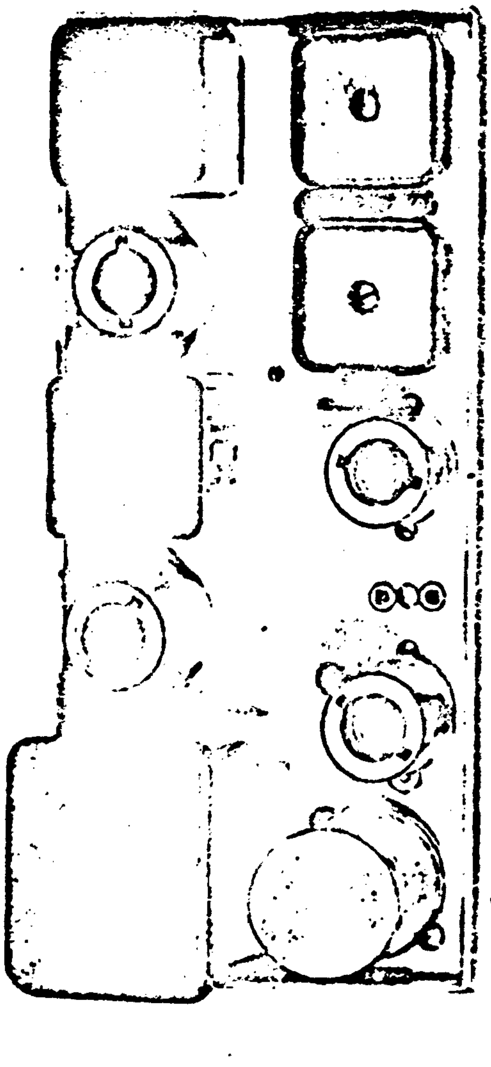


Figure 19. Frequency Translator and Power Amplifier Section of DRRC Display Chassis, Bottom View

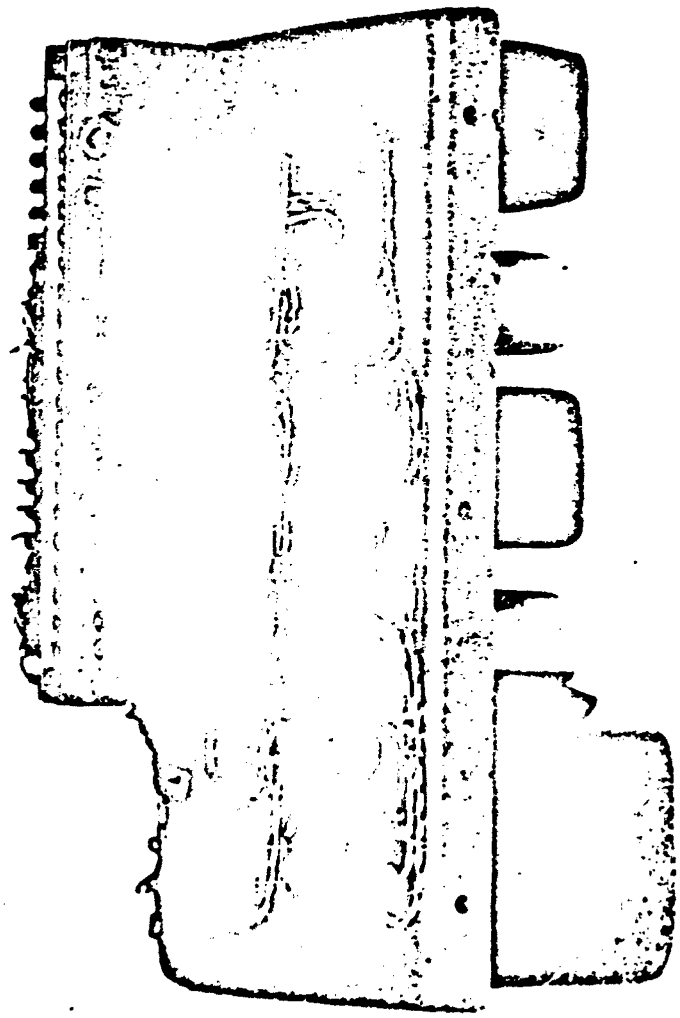


Figure 20. Frequency Translator and Power Amplifier Section of DRRC Display Chassis, Top View

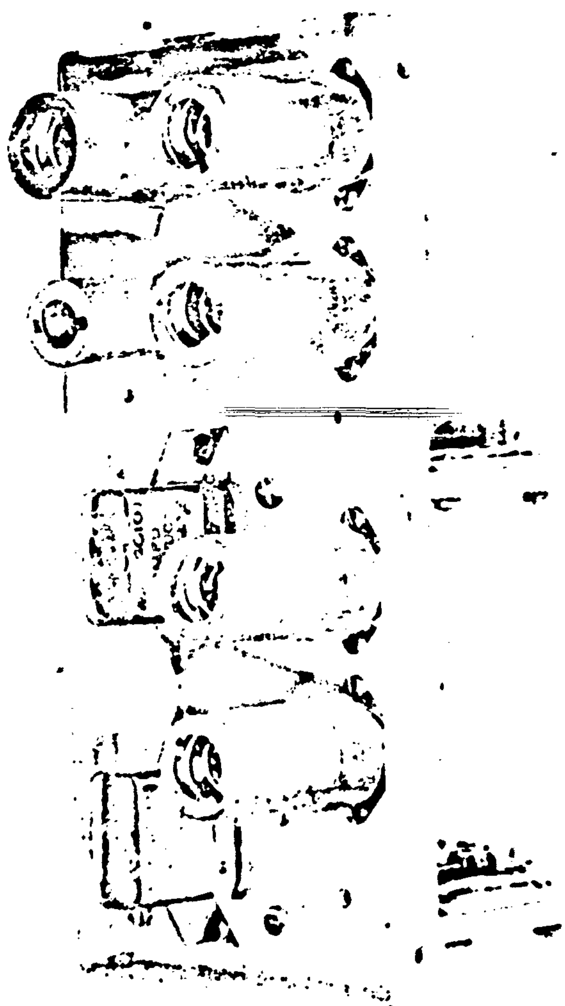


Figure 21. Display Circuits Section of DRRC Display Chassis, Bottom View

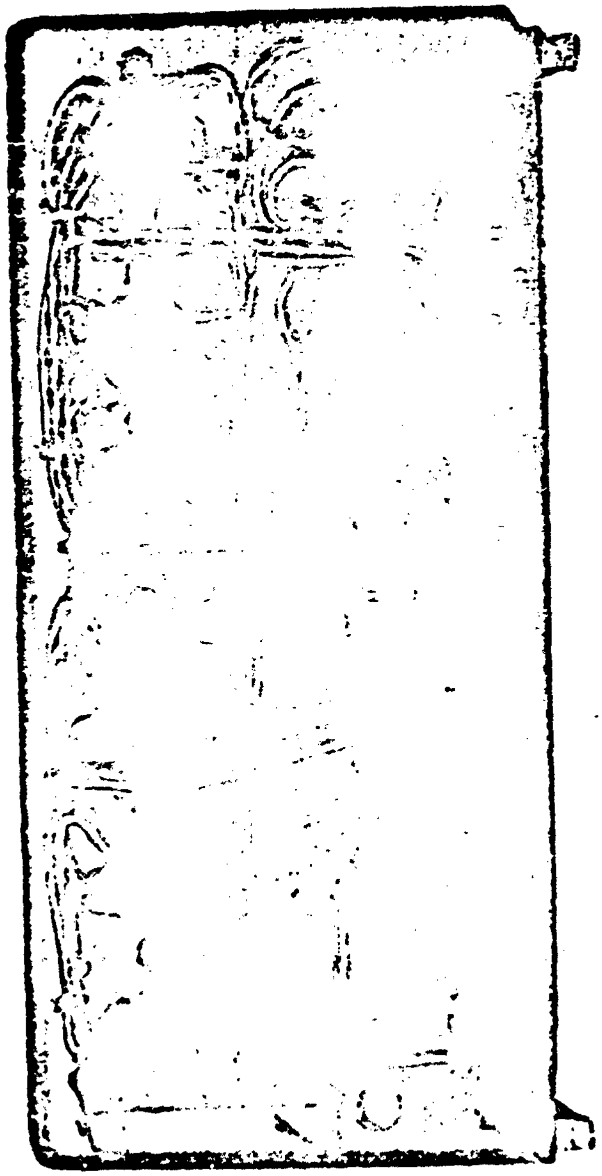


Figure 22. Display Circuits Section of DRRC Display Chassis, Top View

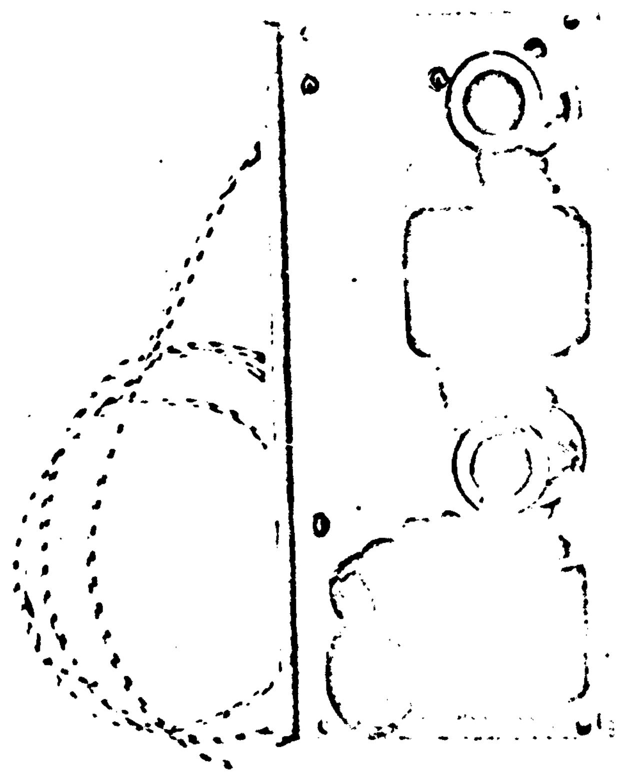


Figure 23, Bias Oscillator Section of DRRC Display Chassis, Bottom View

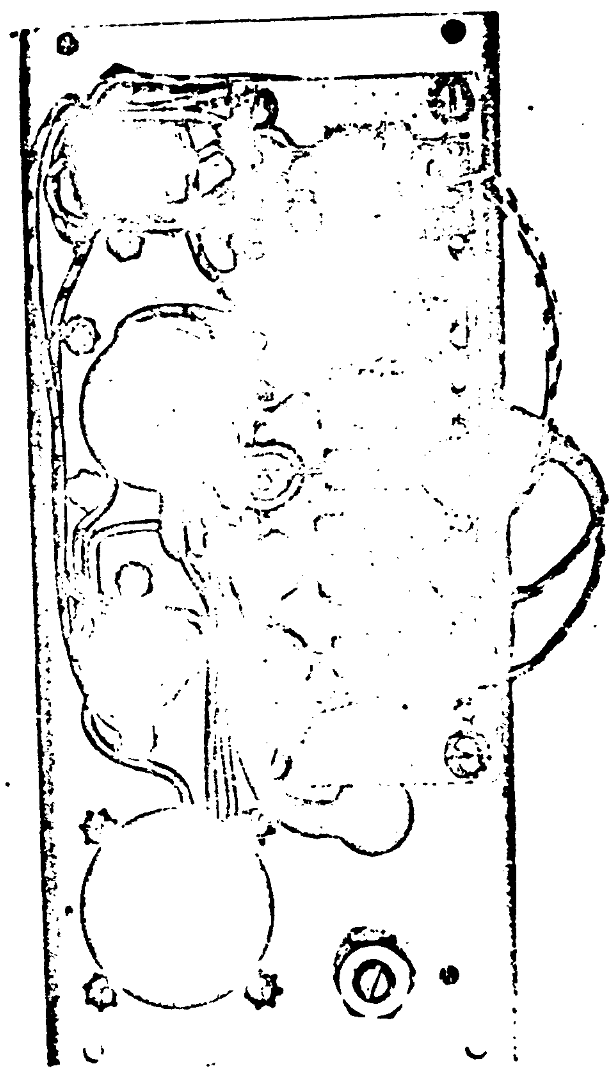


Figure 24. Bias Oscillator Section of DRRC Display Chassis, Top View

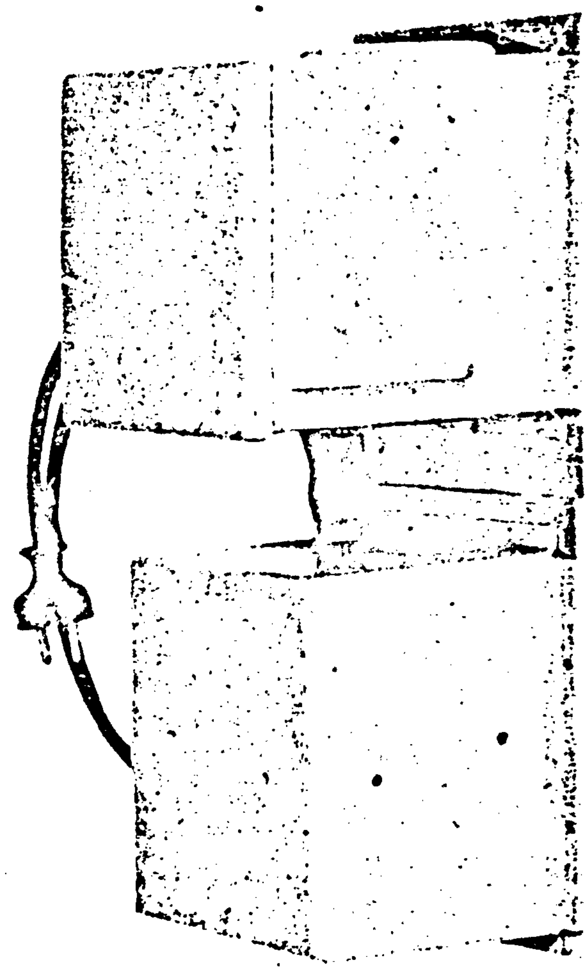


Figure 25. Sampling Commutator with Shield Covers in Place over Motor and Commutator, DRRC

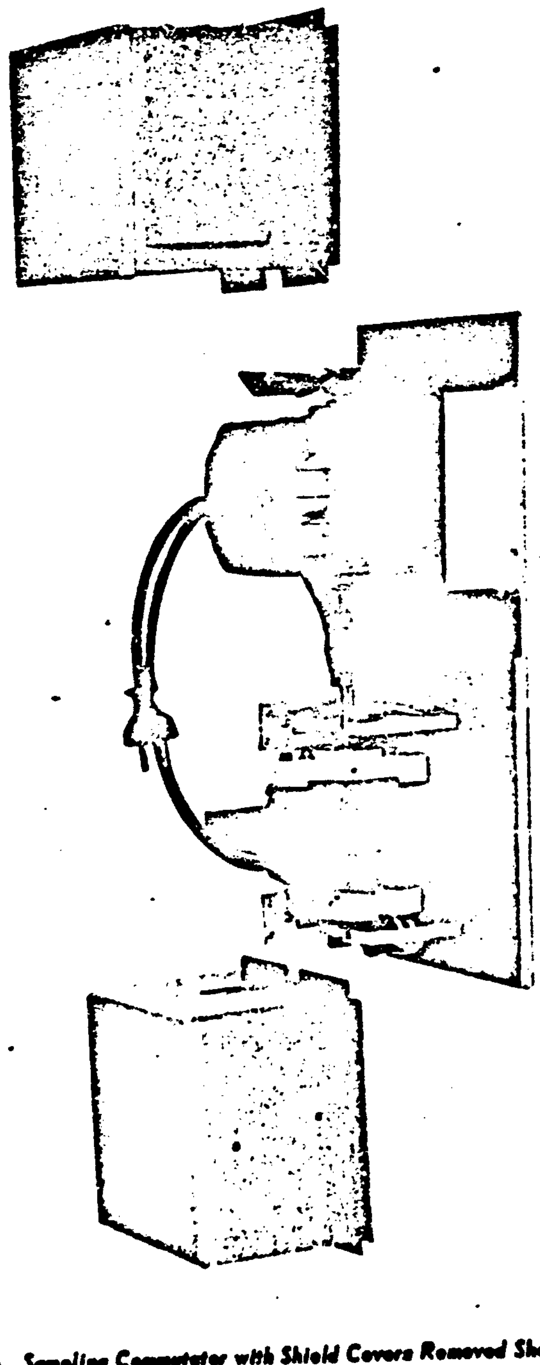


Figure 26. Sampling Commutator with Shield Covers Removed Showing Motor and Commutator Brush and Contact Assembly, DRRC

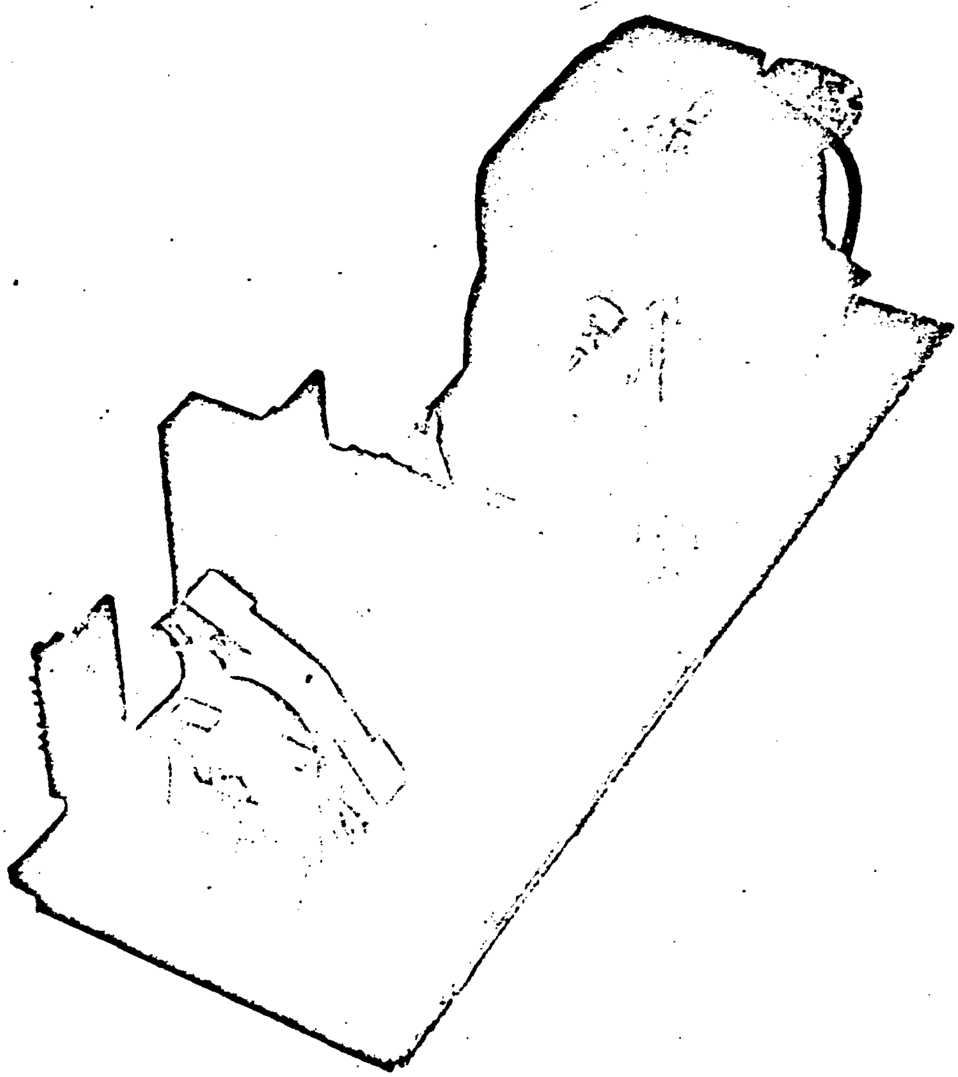


Figure 27. Sampling Commutator Showing Brush and Contact Assembly of Signal Section, DRRC

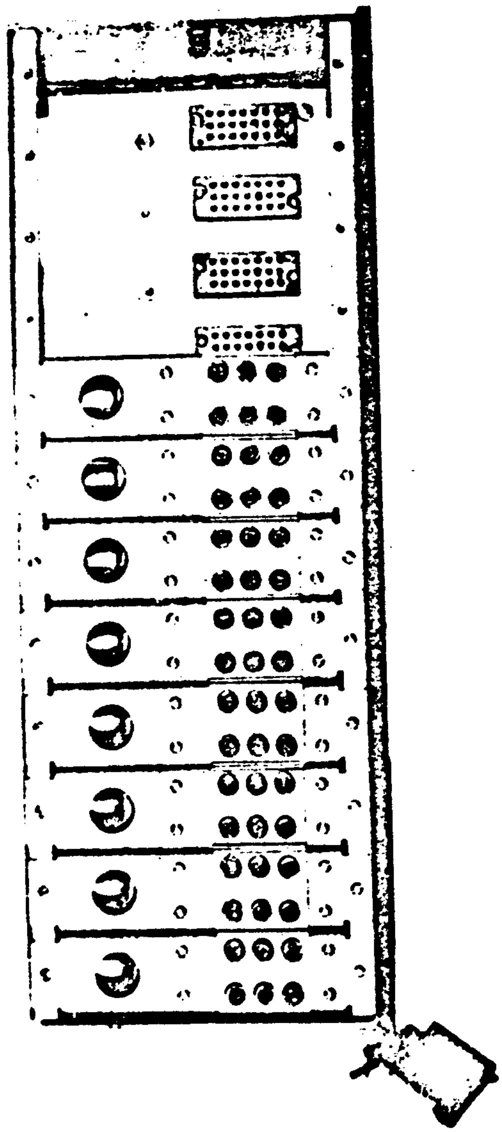


Figure 28. DRRC Filter and Reproduce Amplifier Chassis with Four Plug-in Reproduce Amplifier Units Removed, Front View

Figure 29. DRRC Filter and Reproduce Amplifier Chassis Showing Wiring of Filters and Parallel T Rejection Filters, Top View

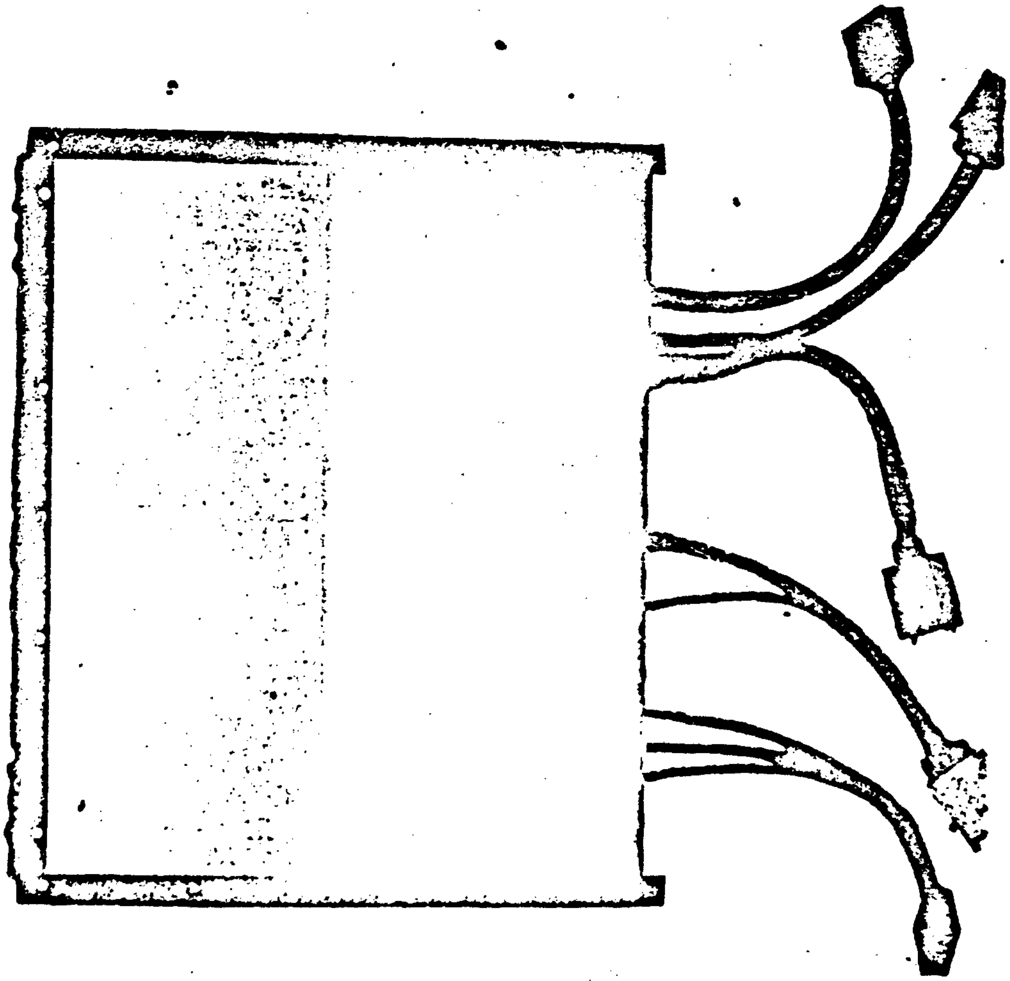


Figure 30. Filter and Reproduce Amplifier Chassis Showing Cables which Connect to the Magnetic Storage Chassis, Bottom View

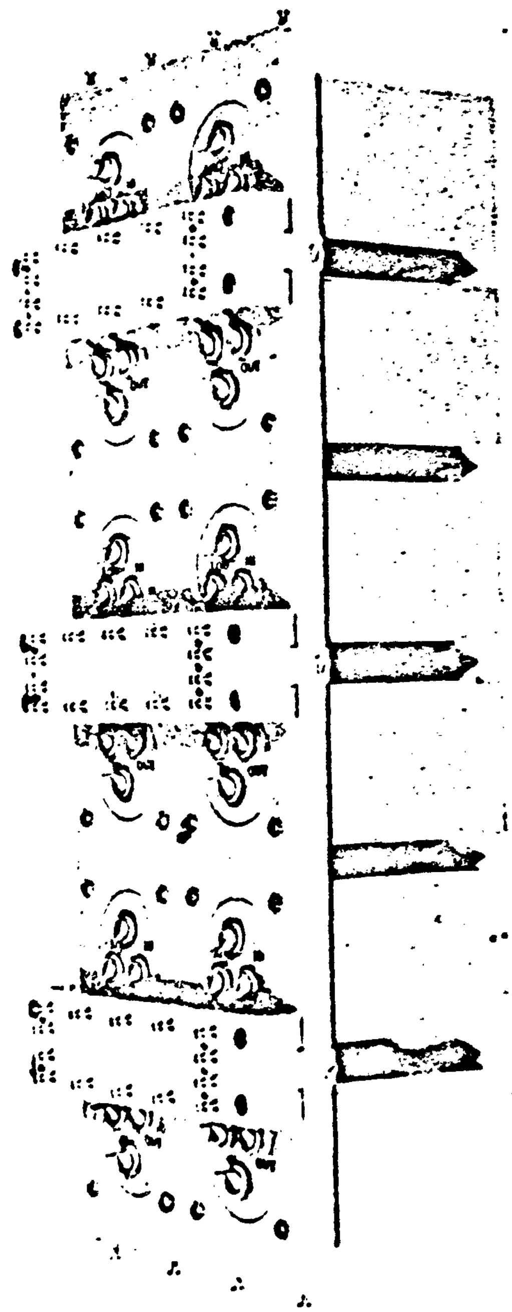


Figure 31. Filter Channel of DRRC Filter and Reproduce Amplifier Chassis Showing the 12 Band Pass Filters Mounted in Place

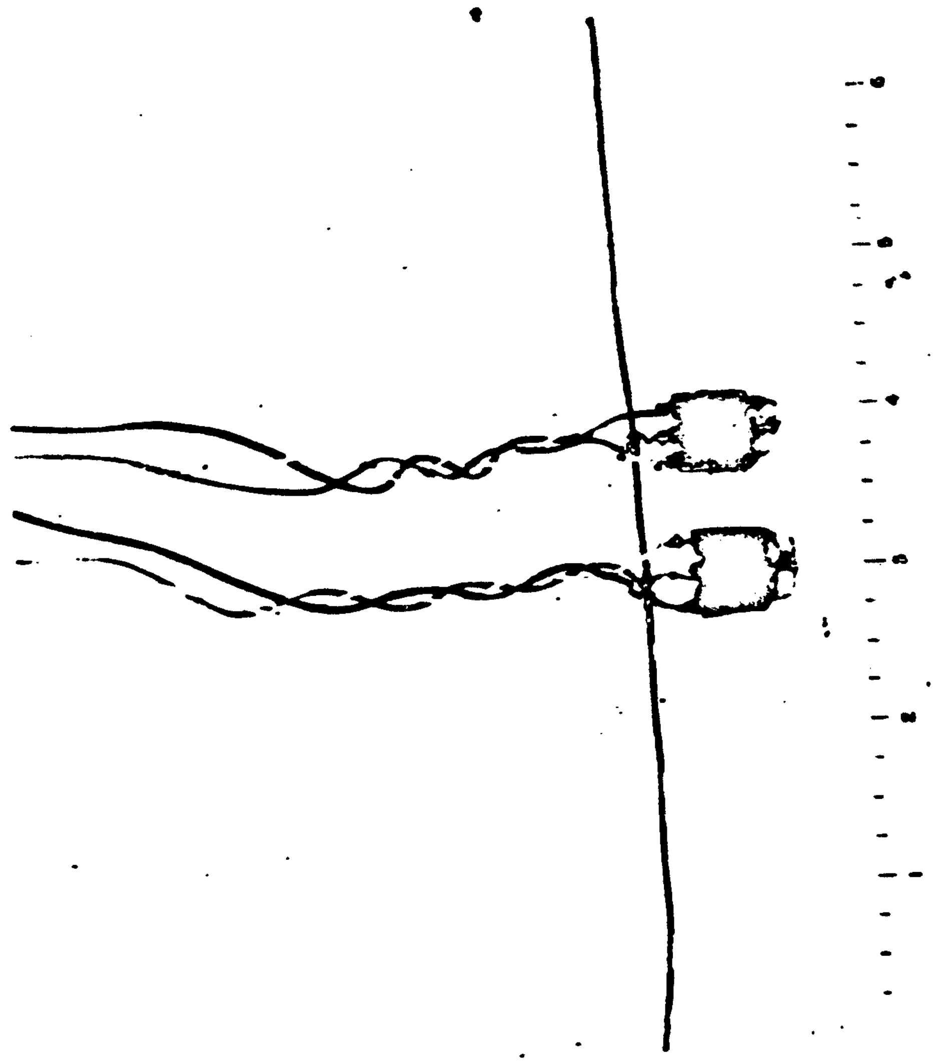


Figure 32. Parallel T Rejection Filters (RC) which Prevent Bias Voltage from Entering Integration Network Circuits, DRRC

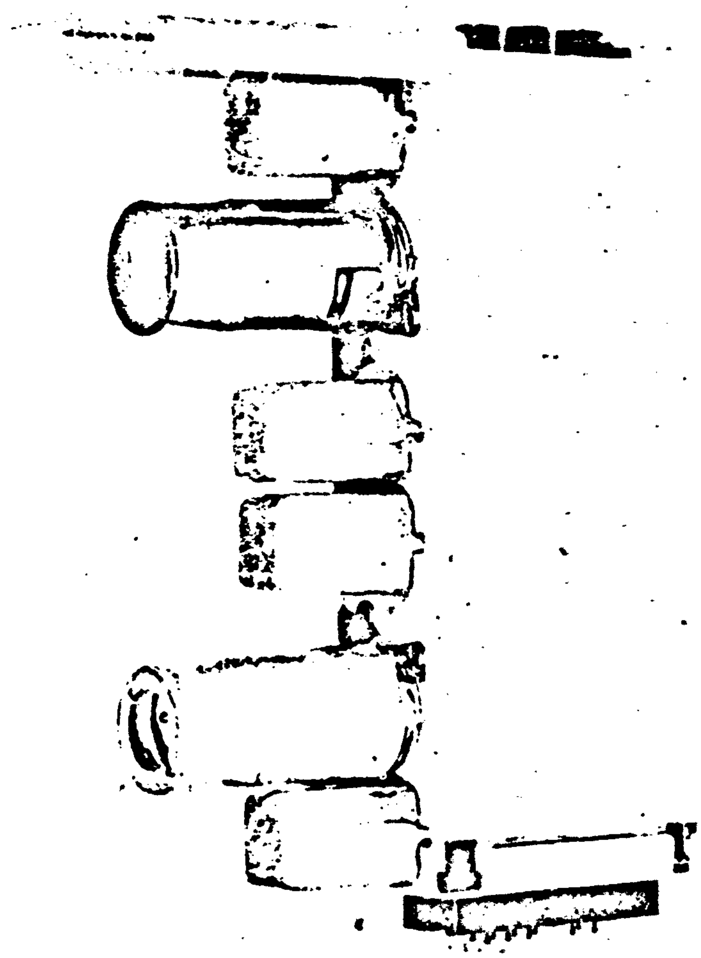


Figure 33. DRRC Reproduce Amplifier Plug-in Unit

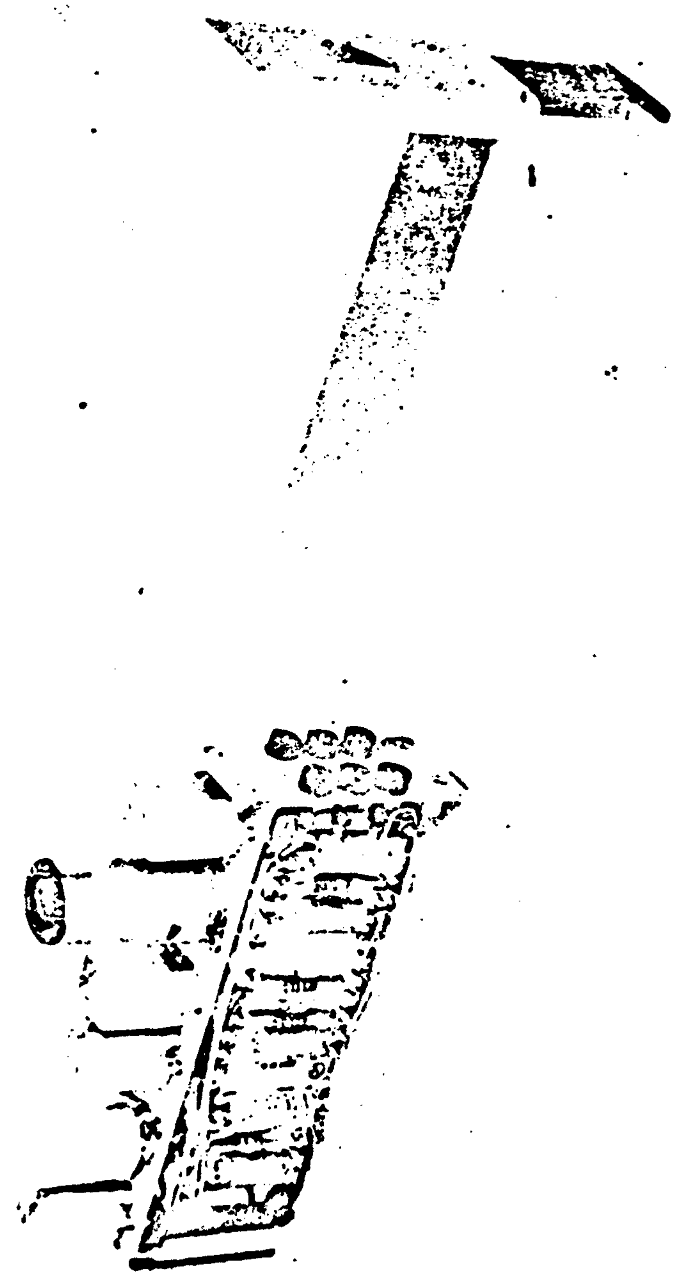


Figure 34. DRRC Reproduce Amplifier Plug-in Unit with Cover Removed

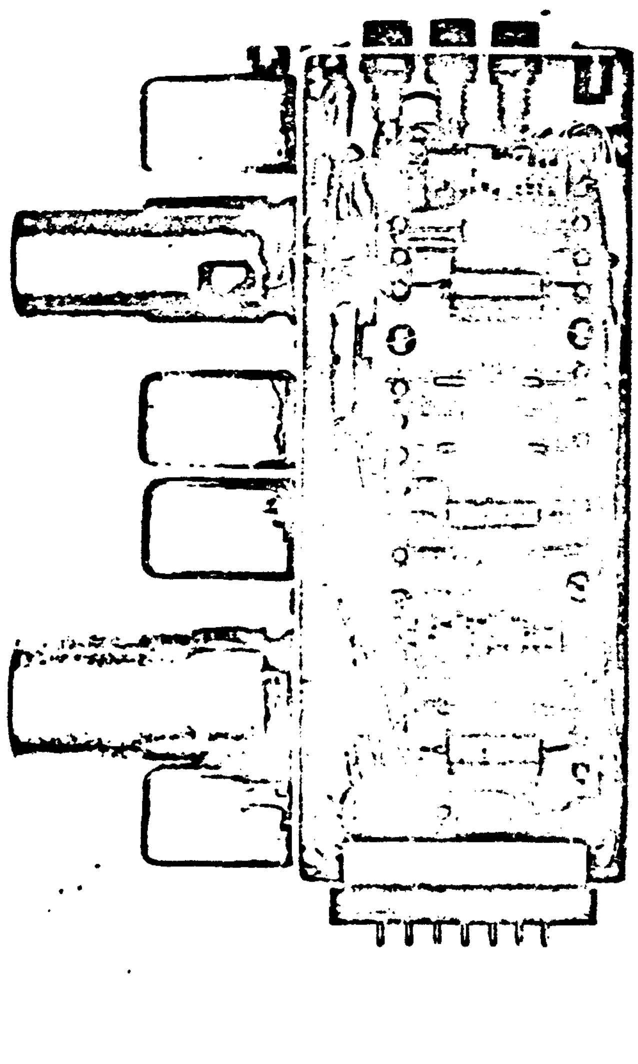


Figure 35. DRKC Reproduce Amplifier Plug-in Unit Showing Placement of Components and Wiring

The range generator potentiometer, the keying pulse micro-switches, and the reproduce unit compensation potentiometer are also in this chassis. The gear train includes two electro-magnetic clutches which enable the speed of the drum to be changed in accordance with the ping repetition interval used. Figures 36 through 38 are front, top and rear views of this chassis showing the location of the various parts. The metal drum which supports the magnetic recording rubber belts was cast of aluminum and machined to size. It is supported by ball bearings at the top and bottom, and is driven through the ring gear. Refer to figure 4 for a view of a magnetic record-reproduce unit and supporting bracket assembly.

g. Accessories.- Two plug-in units are used to replace tubes V-721 and V-709 in the QHB equipment when the Doppler-Range Rate Correlator is used with the QHB. The plug-in crystal oscillator stabilizes the QHB i-f frequency and the other unit provides a cathode-follower output stage to feed the 65-kc audio i-f signal to the Doppler-Range Rate Correlator.

10. Circuit Description.- The Doppler-Range Rate Correlator takes the amplified ping return signal from the QHB and processes it through a group of 12 paralled filters to determine the doppler frequency. The outputs of the filters are stored on a magnetic recording drum capable of storing four consecutive pings. The stored pings are simultaneously reproduced, amplified, rectified and added together along with the envelope of the immediately returning ping. The sum of these five signals is stored in a low pass filter network. Since there is a stored sum of five consecutive ping returns for each doppler channel, a sampling commutator is used to continuously sample all of the low pass filter networks in order to present the information on a single cathode ray tube display.

a. Block Diagram.- A functional block diagram of the equipment is shown in figure 39. A plug-in crystal oscillator unit replaces the master oscillator tube in the QHB in order to stabilize the QHB frequency. With the unicontrol frequency system used in QHB, a stable, drift-free master oscillator results in an equally stable i-f frequency in the receiver.

The plug-in unit replacing V-709 in the QHB audio i-f does not alter the QHB circuit except for providing a cathode-follower output stage to feed the 65-kc i-f signal through the coaxial transmission line to the Doppler-Range Rate Correlator input. The signal is then heterodyned in a mixer stage with the output of a 64.406-kc crystal oscillator to translate it to the frequency band used by the filters. The output of the mixer stage is amplified and fed to the inputs of the twelve filter units.

The 3-db bandwidth of each of the filter units is 36 cycles, corresponding to 2 knots range rate at the QHB transmitting frequency, and they are centered every 36 cycles throughout the band used, thus covering from zero to 22 knots range rate closing in 2-knot steps. The output of each filter unit is connected to a record head on the magnetic recording storage drum. The output of each filter is also fed through a parallel T 10-kc null network to

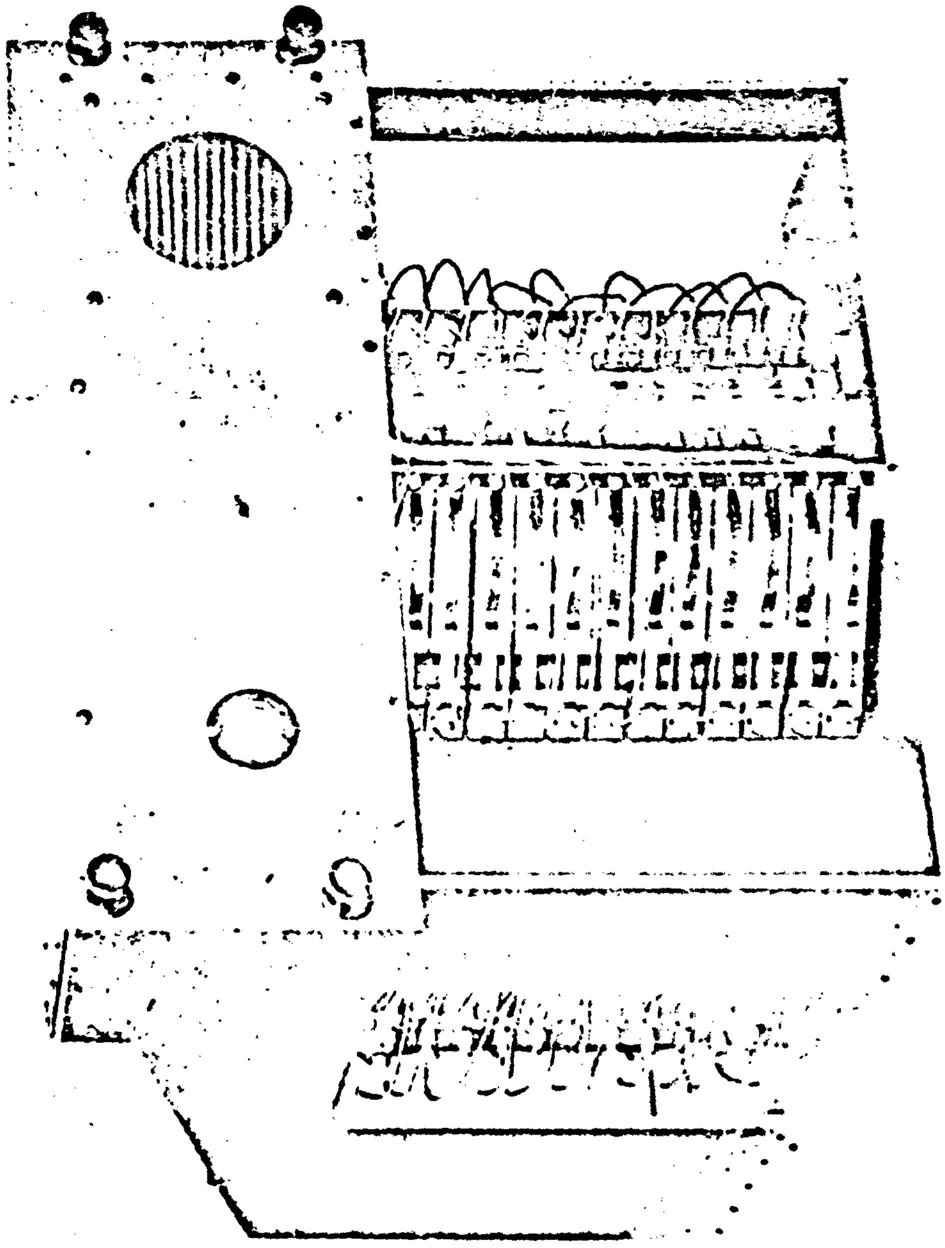


Figure 36. DRRC Magnetic Recording Storage Chassis with Front Panel Removed Showing Spring Loaded Arms Holding Record-Reproduce Heads Against Magnetic Rubber Bands on Drum, Front View

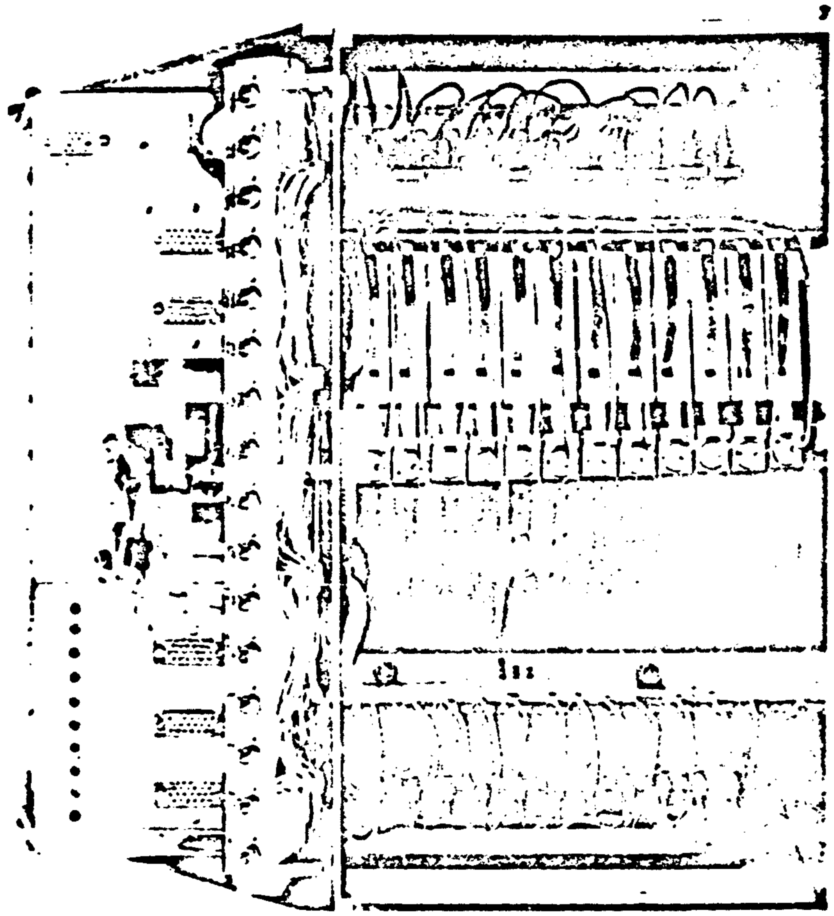


Figure 37. DRRC Magnetic Recording Storage Chassis, Rear View

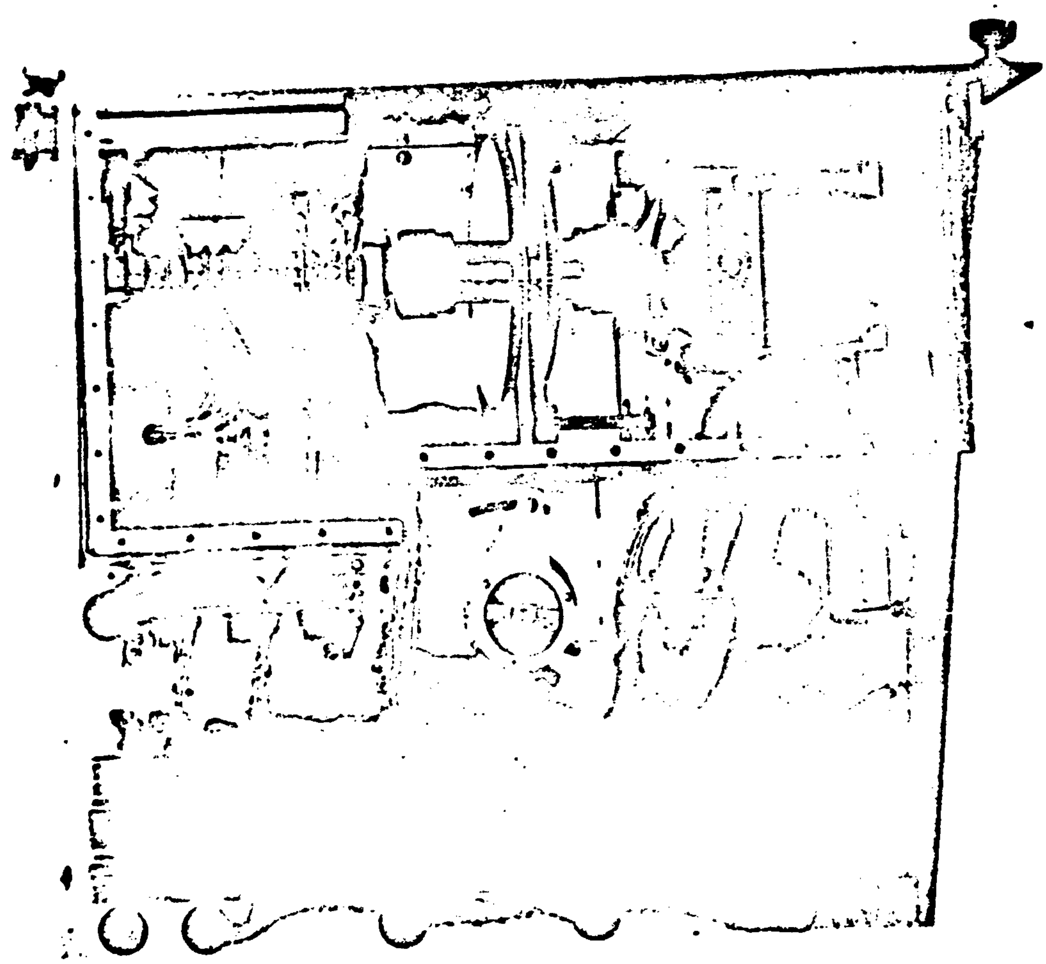
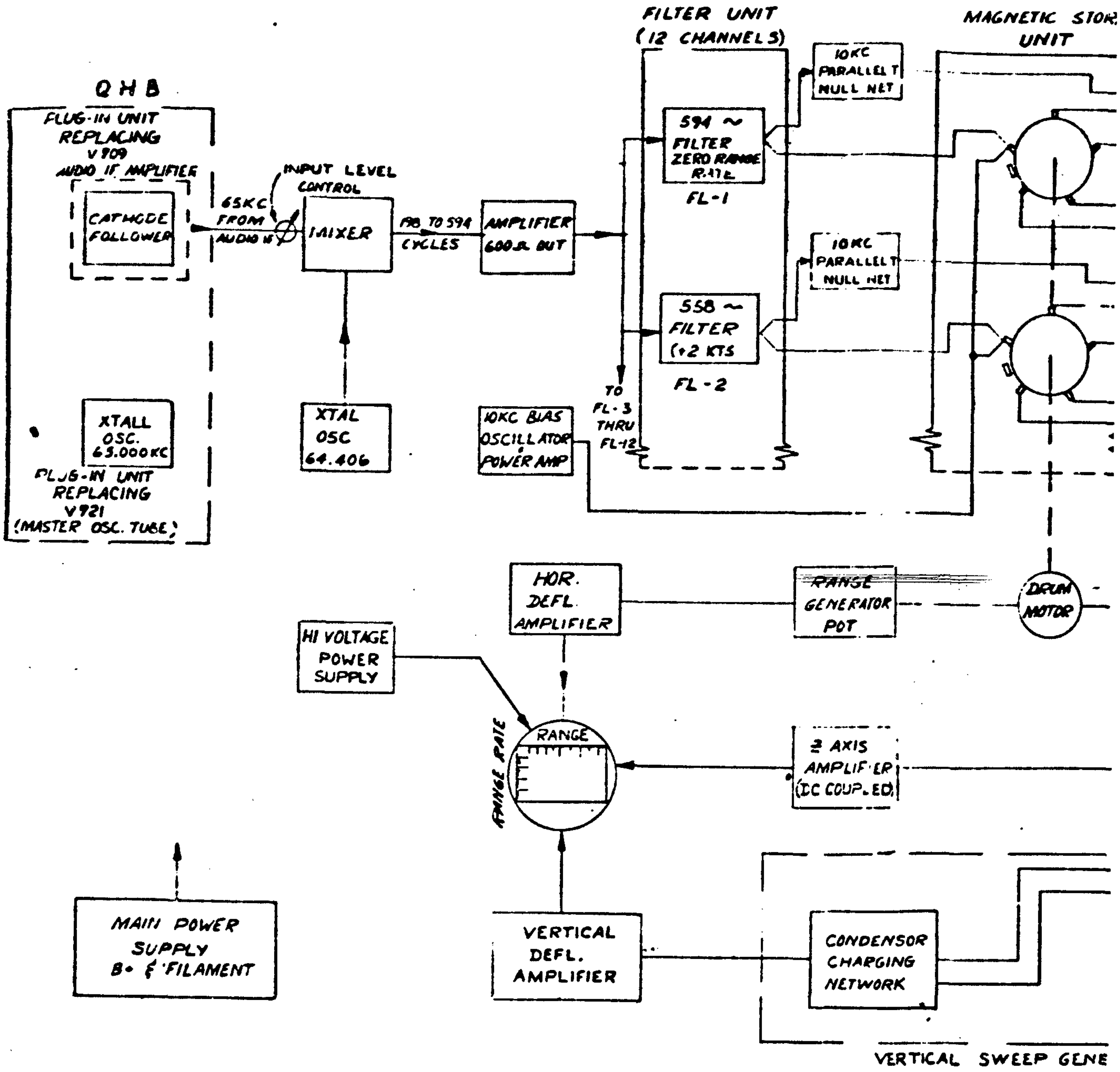


Figure 38. DRRC Magnetic Recording Storage Chassis Showing Drive Motor, Gear Train, Range Potentiometer, etc., Top View


FILTER UNIT (12 CHANNELS)
MAGNETIC STOR. UNIT
QHB
PLUG-IN UNIT REPLACING V709 AUDIO IF AMPLIFIER
CATHODE FOLLOWER
65KC FROM AUDIO IF
INPUT LEVEL CONTROL
MIXER
198 TO 594 CYCLES
AMPLIFIER 600Ω OUT
10KC PARALLEL T NULL NET
594 ~ FILTER ZERO RANGE RATE
FL-1
558 ~ FILTER (+2 KTS
FL-2
TO FL-3 THRU FL-12
XTALL OSC. 65.000KC
PLUG-IN UNIT REPLACING V721 (MASTER OSC. TUBE)
XTAL OSC 64.406
10KC BIAS OSCILLATOR & POWER AMP
HOR. DEFL. AMPLIFIER
RANGE GENERATOR POT
DRUM MOTOR
HI VOLTAGE POWER SUPPLY
RANGE
RANGE RATE
Z AXIS AMPLIFIER (DC COUPLED)
MAIN POWER SUPPLY B+ & FILAMENT
VERTICAL DEFL. AMPLIFIER
CONDENSOR CHARGING NETWORK
VERTICAL SWEEP GENE

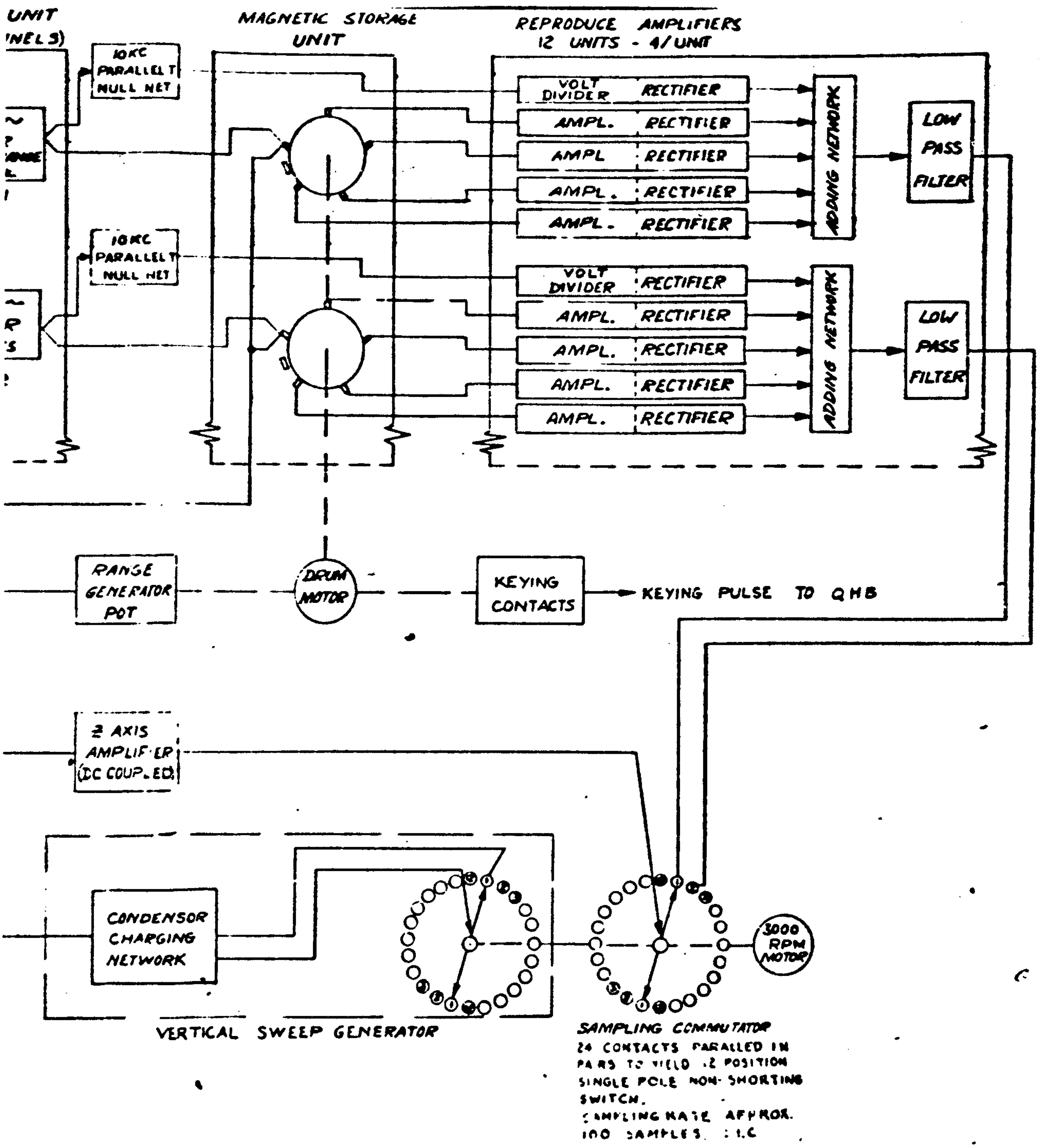


Figure 39. Functional Block Diagram, DRRC Equipment

the reproduce amplifier units. The 10-kc null networks are used to prevent any of the 10-kc bias signals used in the record heads from getting into the reproduce amplifier circuits.

The magnetic storage drum is divided into 12 tracks, one for each of the doppler channels associated with the 12 filter units. The 10-kc bias oscillator and power amplifier furnishes the proper bias current for the record heads. Permanent magnets are used to erase the magnetic tracks just prior to the recording heads. Four reproduce heads are positioned around the periphery of the drum for each of the 12 tracks. These reproduce heads are positioned exactly one ping interval apart on the zero range rate track so that four consecutive echoes from a target of zero range rate would be reproduced simultaneously by the four reproduce heads. The spacing of the four heads on each of the other range rate tracks is basically the same except that each head is advanced toward the record head a distance sufficient to compensate for the closing range rate represented by that track. Thus, if the range rate corresponds to the doppler, so that the echo is recorded on the correct track for the range rate of the target, then four consecutive echoes recorded on any given track will be picked up by the four reproduce heads on that track simultaneously.

The outputs of the four reproduce heads of each range rate track are amplified, rectified, added together, and stored in a low pass filter network. The immediately returning ping which is being recorded is divided down to the correct level, rectified, and added to the four stored pings to give a voltage in the low pass filter which is the result of integrating over five consecutive pings.

Each low pass filter is connected to a segment on the sampling commutator. The output of the sampling commutator is amplified by the d-c coupled Z axis amplifier and used to modulate the intensity of the cathode ray tube beam. The other section of the commutator is used to synchronize the vertical sweep of the CRT display by discharging the sweep capacitor once each sampling cycle. The sawtooth voltage appearing across the capacitor in the capacitor charging network of the vertical sweep generator is converted into a sawtooth current through the CRT vertical deflection coils by the vertical deflection amplifier.

The synchronous motor which drives the magnetic storage drum also operates the micro-switch used for initiating the keying pulse for the QHB. The range generator potentiometer, which is also geared to the drum motor, produces a linearly rising voltage which is converted into a current in the horizontal deflection coils by the horizontal deflection amplifier to produce a horizontal displacement of the beam proportional to the range. (Actually, the linearly rising voltage produces a linearly changing current in the deflection coils, by means of the amplifier, whose time-rate of change is proportional to the round-trip speed of sound in water so that a returning echo brightens the beam at a point whose displacement from the zero, or starting point, is proportional to the range of the target.)

b. Power Supply.- A schematic diagram of the power supply is shown in figure 40. This unit provides all of the plate and filament voltages used by the equipment. The CRT anode is supplied by a separate 5000-volt d-c power supply located on the display chassis. Note that all of the plate current must pass through the focus coil, or the focus rheostat which shunts the focus coil, before being distributed to the various chassis. The filament transformer which supplies voltage to the reproduce amplifiers has an adjustable center tap provided by the 500-ohm potentiometer and is floated a few volts positive with respect to B-. This is done to minimize the possibility of hum pickup in the reproduce amplifiers due to the filament-to-cathode leakage. The component values, voltages, and currents are indicated on the schematic diagram.

c. Display Chassis.- This chassis contains the cathode ray tube, its associated display circuits, the signal frequency translator and amplifier, the 10-kc bias oscillator, the sampling commutator, and the CRT 5000-volt anode supply. It also contains the various operating controls, such as power switch, range interval selector switch, storage switch, etc, that are not necessarily an integral part of these circuits but are located on this chassis for operational convenience. Figure 41 is a schematic diagram of the display chassis. This schematic does not include the 117-volt a-c power or filament power wiring since this wiring is shown in figures 48, 49 and 50.

The signal from the QHB comes in through P-203/14 to the frequency translator and amplifier unit shown in the upper left portion of the schematic. The 0.01 µf coupling capacitor and 125-mh choke are arranged to enable the coaxial line to carry plate voltage to the plug-in cathode-follower output stage in the QHB as well as signal from the cathode follower to the frequency translator input. A 12AY7 arranged as a carrier balanced mixer is used to convert the 65-kc incoming signal to 594 cycles. The 64.406-kc local oscillator is crystal controlled to achieve maximum frequency stability since a frequency change of only 0.05% in the local oscillator would put the signal in the wrong doppler filter. The push-pull 12AU7 amplifier can provide up to 1 watt of output power across the 600-ohm line, which is more than sufficient to drive the 12 record heads through the doppler filters.

The 10-kc bias oscillator unit shown at the lower left of the schematic obtains its plate supply through a potentiometer to provide a means of adjusting its output level. The 12AU7 push-pull output amplifier provides sufficient 10-kc current to bias the 12 recording heads.

The display circuits are shown at the right hand side of the schematic with the Z axis amplifier at the top and the sweep circuits directly below. The horizontal and vertical sweep circuits are alike except for the method of generating the sweep voltage. The horizontal sweep voltage is obtained from a mechanically driven linear potentiometer located in the magnetic storage unit. This potentiometer is connected through terminals 9, 10, and 11 on P-202, with terminal 11 being connected to the arm. The vertical sweep is generated by a 0.1 microfarad capacitor which charges toward the 255-volt

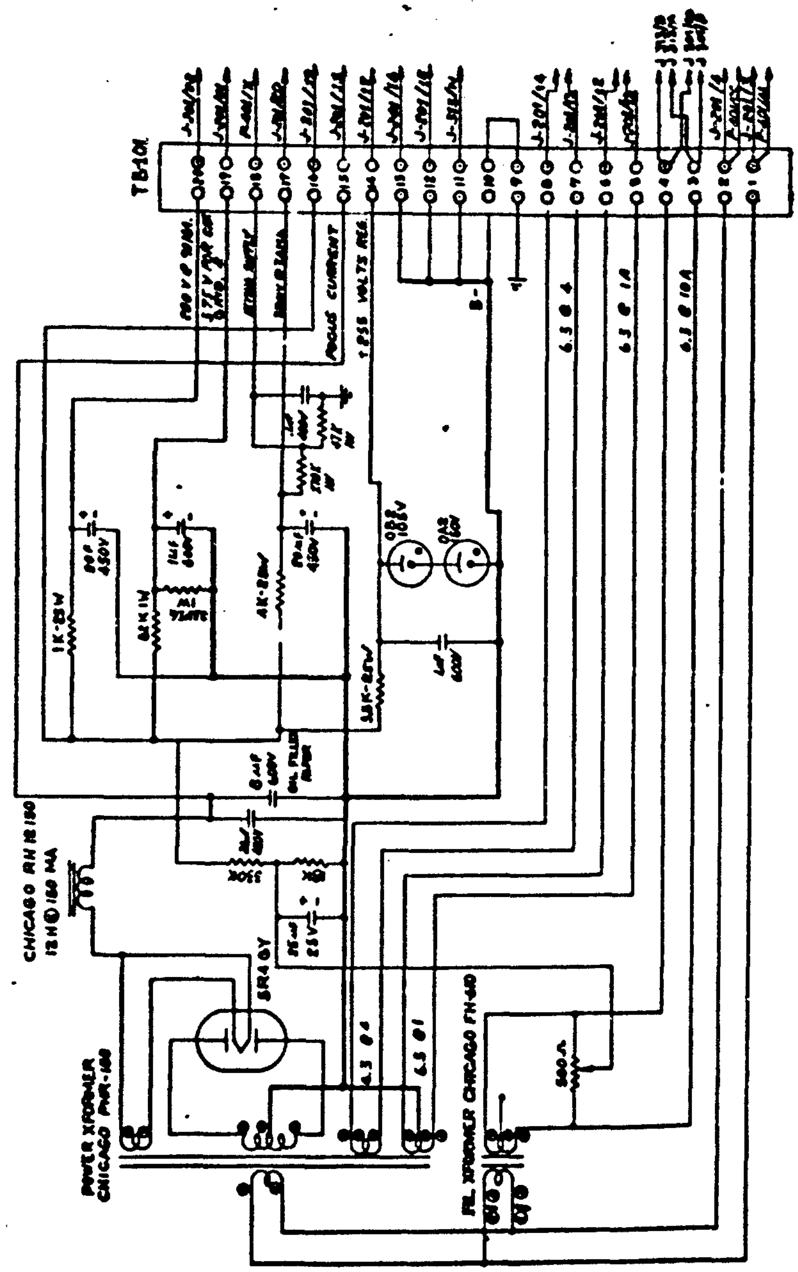


Figure 40. Schematic Diagram, DRRC Power Supply

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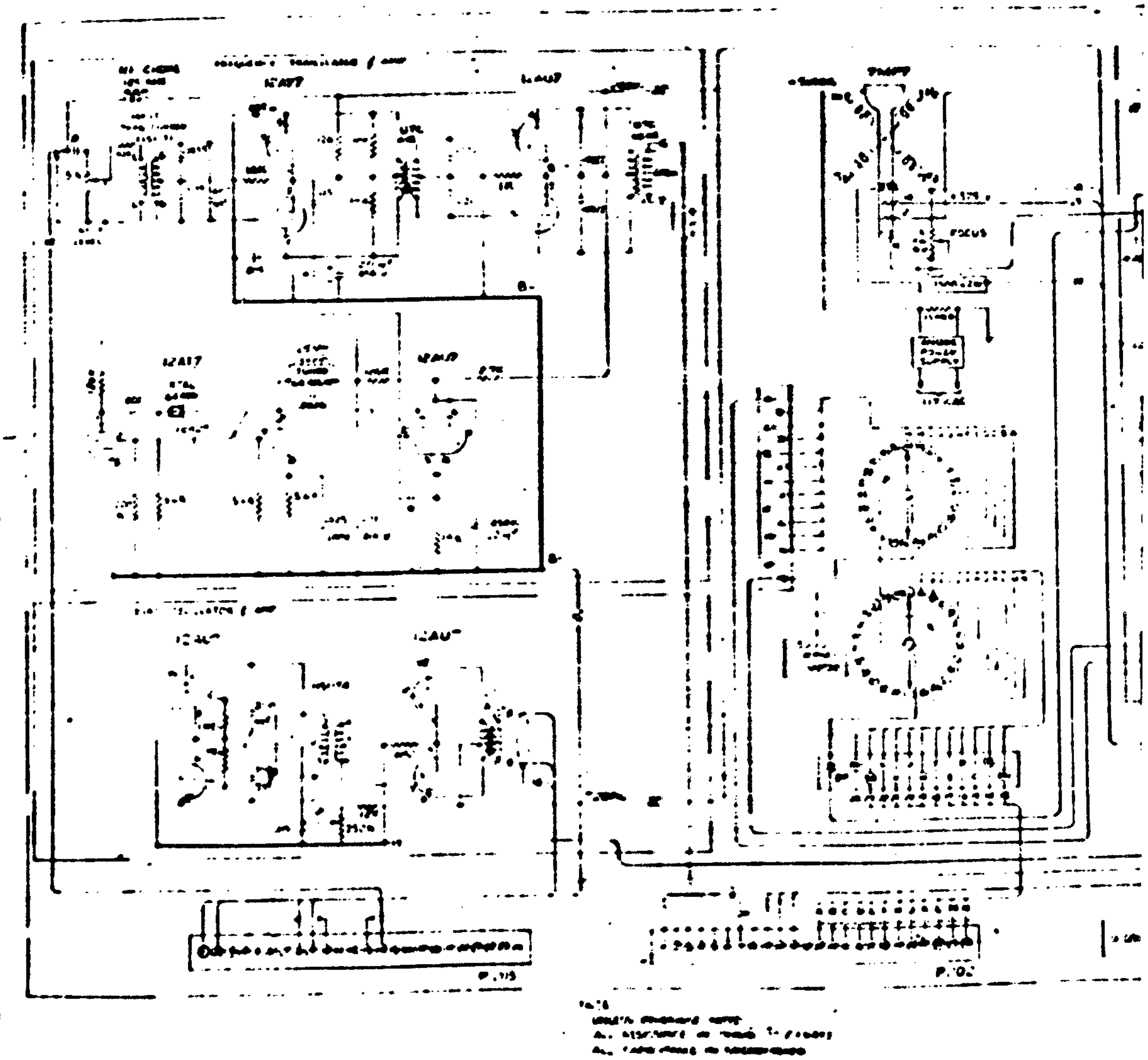

Figure 41

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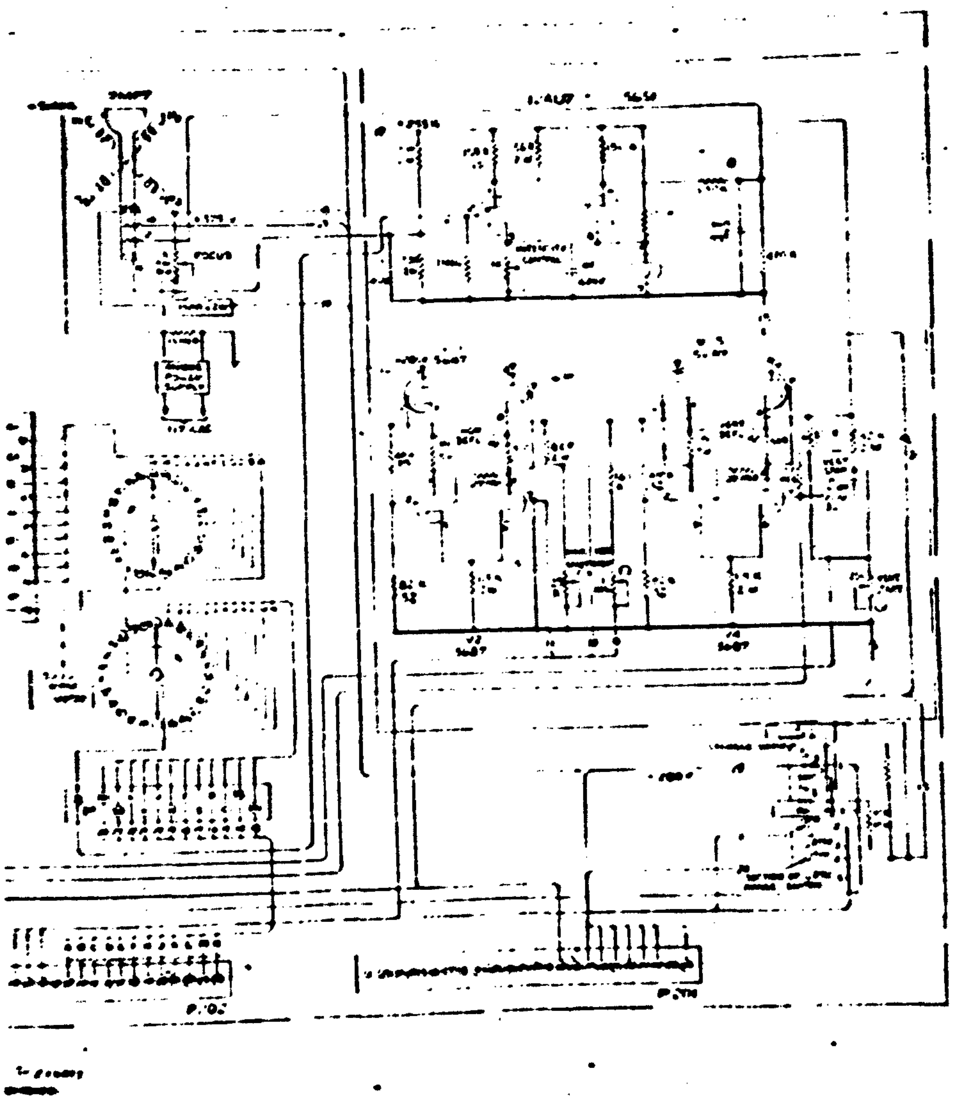


Figure 41. Schematic Diagram, DRRC Display Chassis

supply line and is discharged by a section of the sampling commutator once each sampling cycle. The sweep circuits are basically paraphase bridge circuits with a triode used as a variable resistance element in each of the four bridge legs. The bridge is unbalanced by the sweep voltage generated at the input grid. The input triode drives its mate in an inverse direction, exaggerating the unbalance, through the common cathode coupling aided by the direct coupling provided by the 2.7-megohm resistor. The unbalance current flowing through the deflection coils creates bias voltages across the 300-ohm bias resistors in the plate-cathode leads which unbalances the triodes in the upper arms of the bridge in the direction to help increase the unbalance current flowing through the deflection coils. This particular type of deflection circuit is quite efficient since it provides an unusual amount of deflection current for a given current drain from the plate supply.

The d-c coupled Z axis amplifier modulates the CRT beam in accordance with the output of the sampling commutator. The cathode of the CRT is held positive with respect to the grid by means of a voltage divider from the +255-volt line. The quiescent grid voltage of the CRT is determined by the setting of the intensity control, which is normally adjusted to keep the beam current just cut off. Since the output of the commutator, if any, is always a positive voltage, the most linear region of amplification is occupied by positive input voltages when the intensity control is adjusted for beam current cut-off. The frequency response of the Z axis amplifier was made constant up to approximately 40 kc to enable the discrete samples to be distinguished (the samples are approximately 0.8 milliseconds in duration with the spaces between samples approximately 0.2 milliseconds).

d. Filter and Reproduce Amplifier Chassis.- The schematic diagram of this chassis is shown in figure 42. The signal from the amplifier in the display chassis comes in through K and L of P-313 and is fed to the inputs of the filters through 600-ohm isolating resistors. The 600-ohm output impedance of the amplifier in series with the 600-ohm isolating resistor matches the 1200-ohm terminating impedance of each filter throughout the pass band of that filter. The output of each filter is connected through a 1200-ohm termination resistor to its record head since the impedance of the record head is low at these frequencies. The bias current is connected to each record head through an isolating capacitor whose reactance matches the reactance of the head at the bias frequency to provide maximum transfer of energy at the bias frequency. Since the reactance of the capacitor is large at the signal frequency, the recording heads are effectively isolated from one another for the signal. The 10-kc parallel T null networks, of which a typical configuration is shown, offers no attenuation to the signal frequency, but prevents the 10-kc bias frequency from entering the reproduce amplifier units.

A schematic diagram typical of the filter units, with filter data, is shown in figure 43; figure 44 is a schematic typical of the 12 reproduce amplifier plug-in units. These units connect to jacks J-301 through J-312 shown on figure 42. The signals from the four reproduce heads - of the range

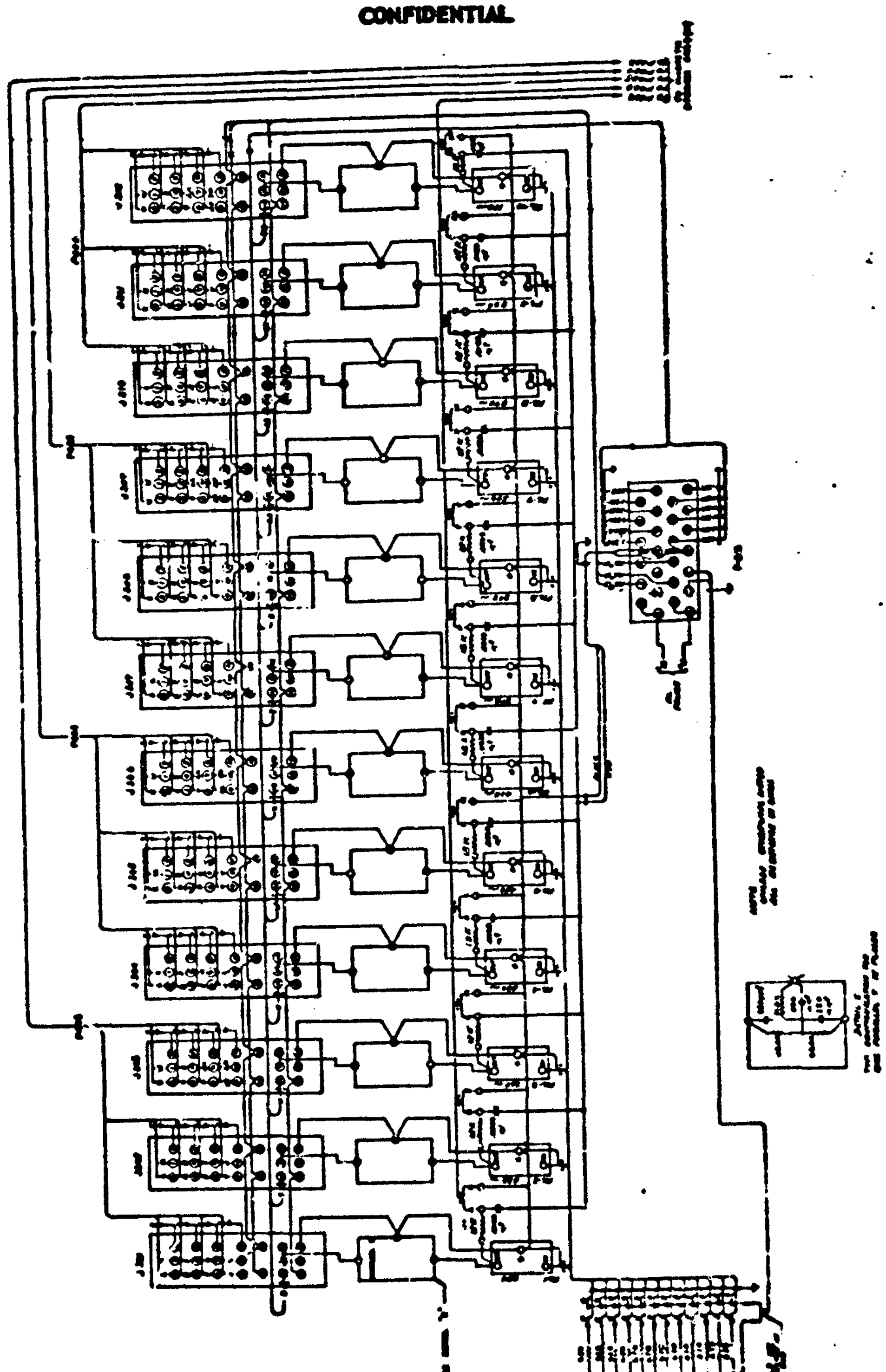
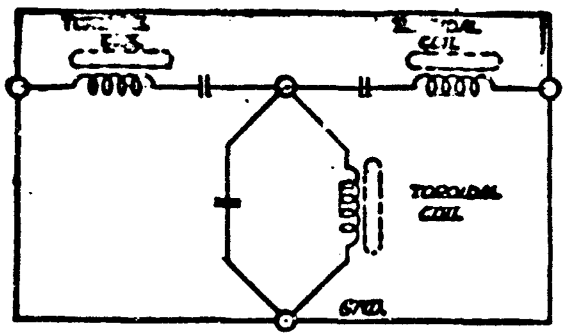


Figure 42. Schematic Diagram, DRRC Filter and Reproduce Amplifier Chassis



FILTER UNIT
(12 UNITS IN LOOP.)

FILTER DATA -
TYPE: BANDPASS, CONSTANT K, FULL T SECTION
IMPEDANCE: [illegible] OHMS
BPSS RESPONSE: DOWN 3 db at [illegible] CYCLES FROM CENTER FREQ. (BANDWIDTH OF 36 CYCLES). DOWN AT LEAST 12 db AT ± 36 CYCLES (CENTER FREQ. OF ADJACENT FILTERS)
MANUFACTOR: BURNELL & CO.

CHANNEL NO	RANGE RATE	FILTER CENTER FREQ.	MFG. SERIAL NO.
1	0	594 CYCLES	811143
2	2	558 CYCLES	811144
3	4	522 CYCLES	811145
4	6	486 CYCLES	811146
5	8	450 CYCLES	811147
6	10	414 CYCLES	811148
7	12	378 CYCLES	811149
8	14	342 CYCLES	811150
9	16	306 CYCLES	811151
10	18	270 CYCLES	811152
11	20	234 CYCLES	811153
12	22	198 CYCLES	811154

Figure 43. Filter Unit Schematic and Filter Data, DRRC

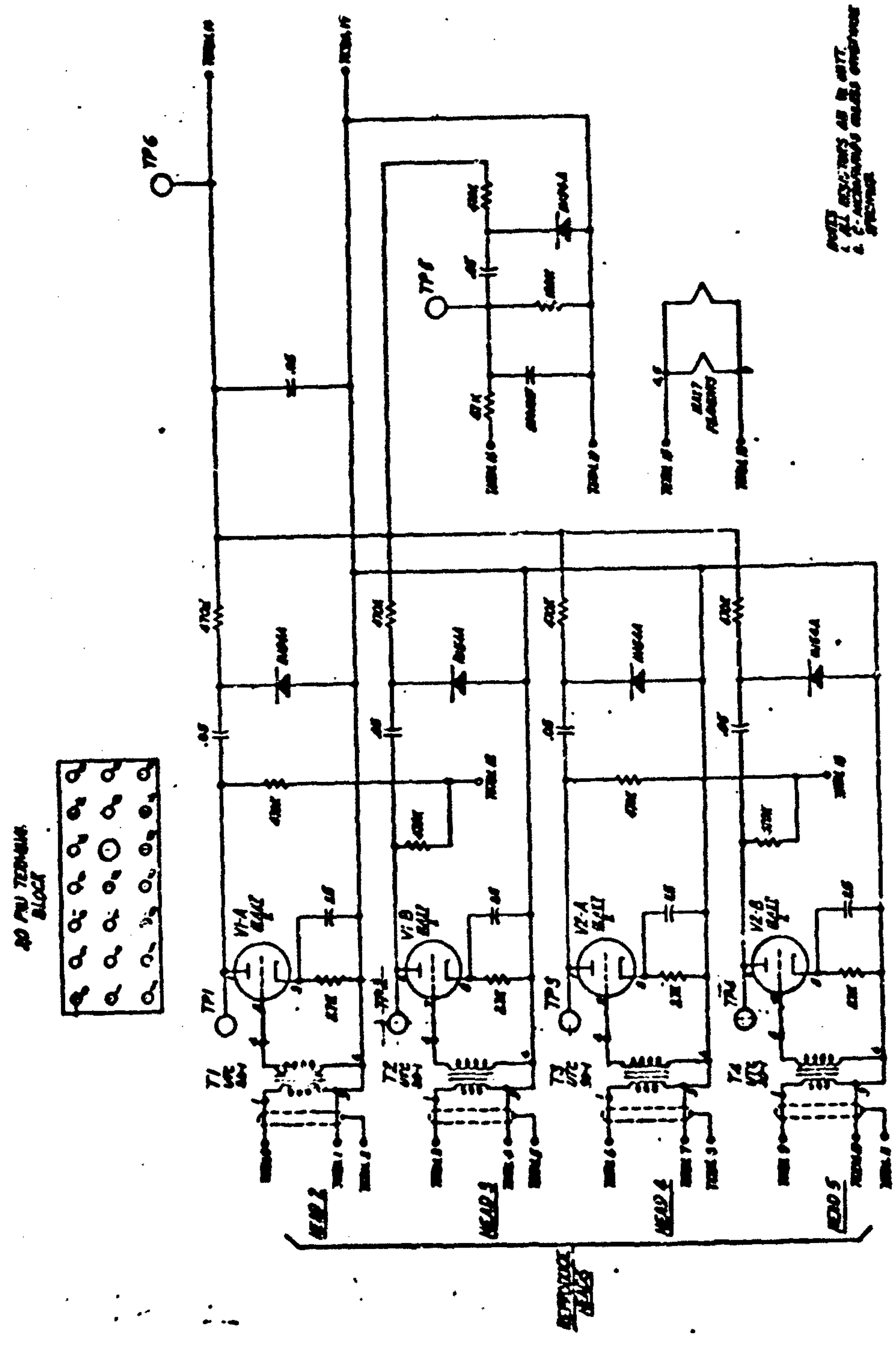


Figure 44. Reproduce Amplifier (Plug-in Unit) Schematic, DRRC

rate track associated with the particular plug-in unit under consideration - are amplified by the 12AX7 triode sections, after suitable step-up through the input transformer, rectified by the IN54A germanium diodes, and the rectified signals are added together in the low pass filter composed of the 0.05 µf capacitor. The direct signal from the filter associated with a particular plug-in unit comes through the parallel T null network, shown in figure 42, to terminals 16 and 19 on figure 44 where it is adjusted to the proper level by the voltage divider, rectified, and added with the other four rectified signals. The voltage divider presents to the rectifier the same impedance as the output impedance of the 12AX7 triode sections so that all rectifier circuits operate exactly the same and the adding circuit sees the same output impedance from all five rectifiers. This insures correct operation of the adding circuit. A separate plate supply for each of the 12AX7 tubes is brought through the storage switch on the display chassis to enable one or both of the 12AX7 tubes to be disconnected to prevent amplification. This enables the operator to select the number of pings to be integrated over, 1, 3, or 5. In the 1 position of the switch the direct signal is the only one used and range rate correlation is prevented, the system operating as a frequency scan receiver. In the 3 position two stored pings are used with the direct signal. In the 5 position all stored pings are utilized. A wiring diagram of the storage switch circuit is shown in figure 45.

e. <u>Magnetic Storage Chassis</u>.- Figure 46 is an electrical diagram of the magnetic storage chassis. A potentiometer is connected across each of the reproduce heads as a variable load resistance to enable the output level of all of the heads to be equalized. (Twisted pair, shielded leads are used for the signal circuits throughout the equipment. The shields are grounded to the equipment chassis at only one place.) Details of the magnetic record-reproduce heads are given in paragraph 8d, details of the storage drum in 8c, and information on the magnetic recording rubber belts used as a medium are given in 8b.

The magnetic recording drum is driven by a 1200 rpm synchronous speed motor through either of two electro-magnetic clutches and their associated speed reducing gear trains. Selection of which clutch is used, by means of the range selector switch on the display chassis, determines the speed of the drum. One speed is correct for the 3750-yard range ping interval while the other is correct for the 1500-yard range. A bridge type selenium rectifier and RC filter is used to obtain the proper d-c voltage for the clutch operation.

The range generator potentiometer and the cam operating the keying switches are driven through the same gear train that operates the drum. Two micro-switches are used to initiate the keying pulses, one being used for the 3750-yard range interval, the other for the 1500-yard interval. The QHB has a fixed time delay in keying which is independent of range interval, but in this equipment the delay is a fixed percentage of the drum circumference (a constant angle) which varies in time as the drum speed varies. Thus, two microswitches are used, and these are positioned slightly different in relation to the operating cam so that the range sweep on the cathode ray tube

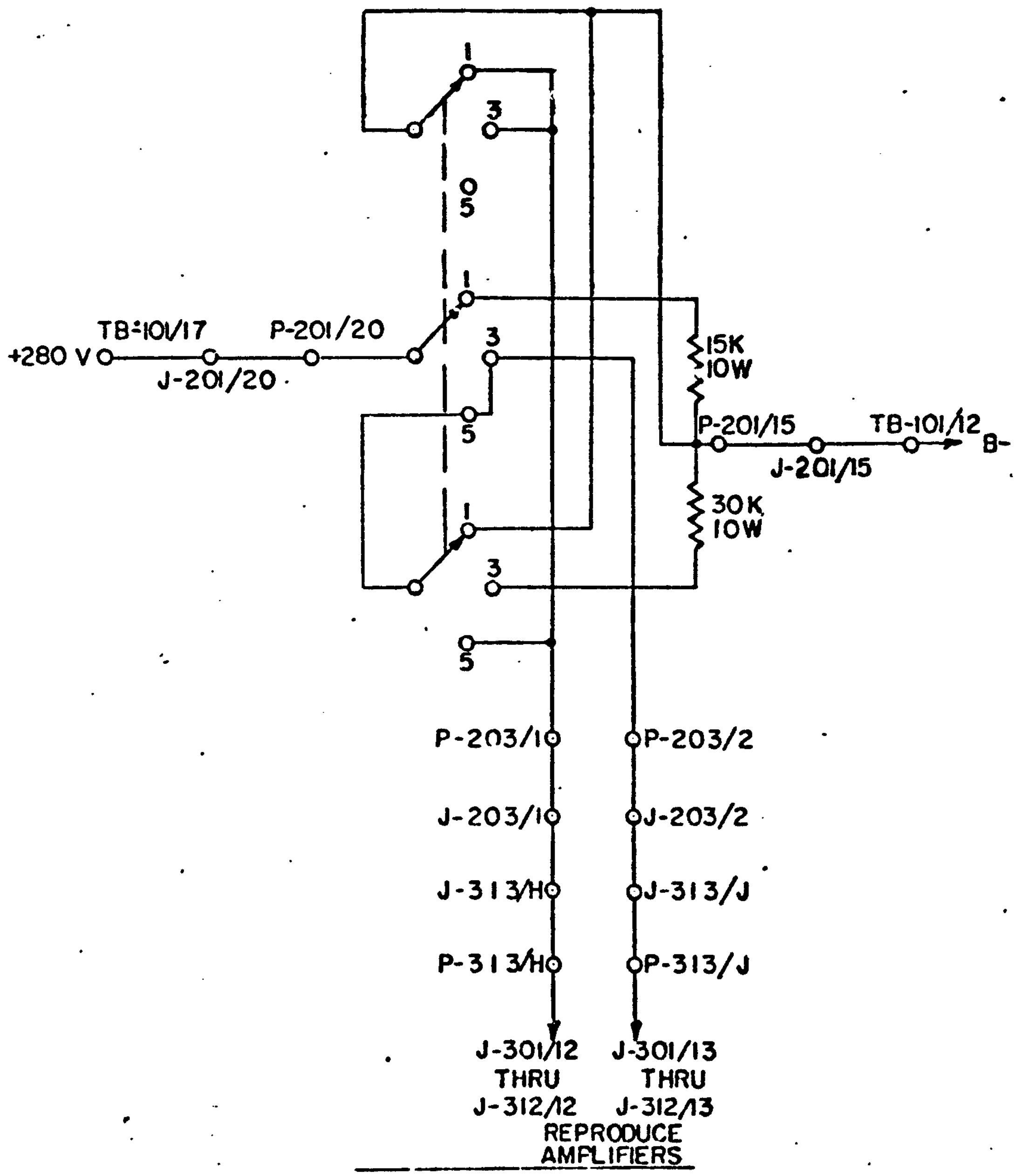


Figure 45. Storage Switch, DRRC

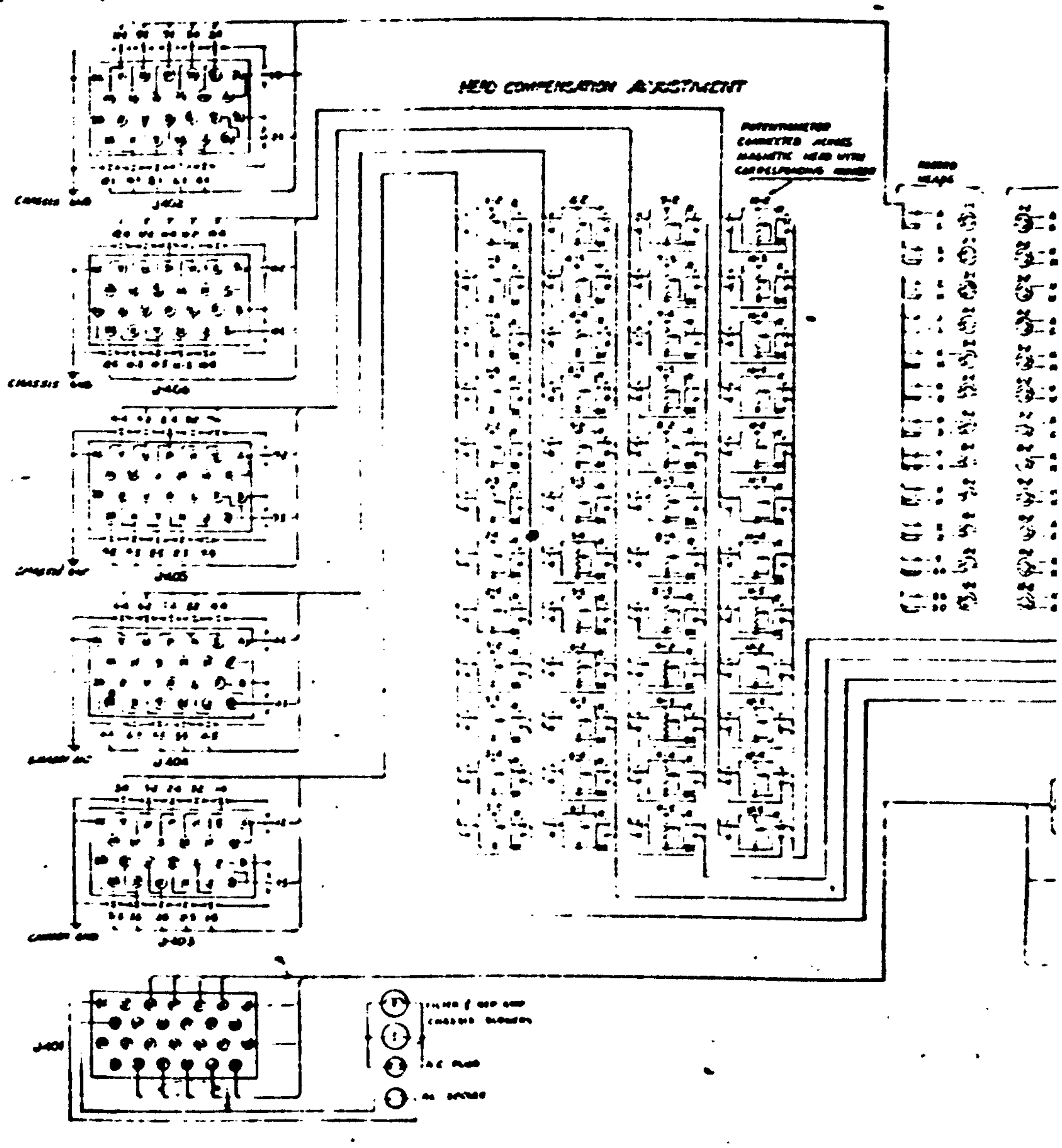


Figure 46. I

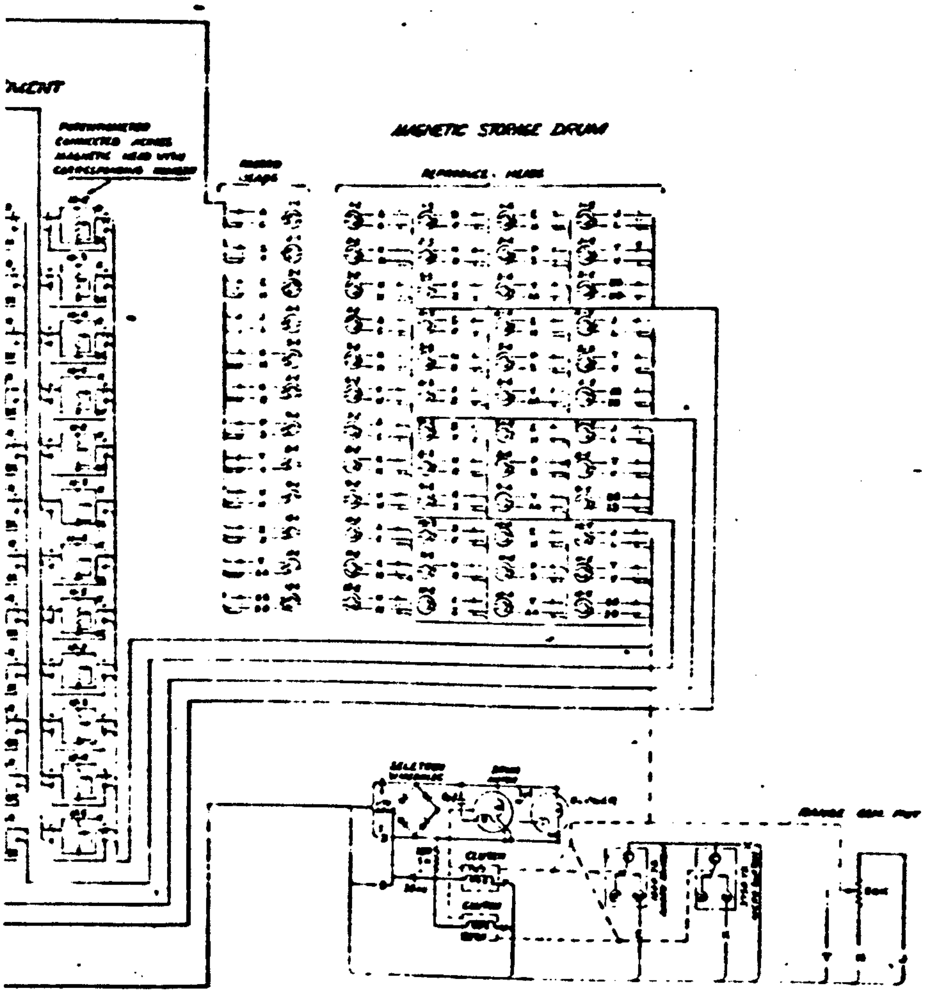


Figure 46. Electrical Diagram, DRRC Magnetic Storage Chassis

will always start at a position which will cause the outgoing ping of the QHB to occur at zero time on the display.

f. Range Switch.- A wiring diagram of the range switch showing all of its functions is given in figure 47. One section selects the correct clutch to drive the drum, the second section selects the proper micro-switch to use, while the third section energizes the correct set of lamps to illuminate the range scale being used.

g. Wiring and Interconnection Diagrams.- Figure 48 is a ladder schematic showing the distribution of the 117 volts a-c primary power, figure 49 is a schematic of the 6.3 volts a-c filament power distribution, and figure 50 is a wiring diagram of the filament and power distribution shown schematically in 48 and 49.

Figure 51 is a complete interconnection wiring diagram showing the connections between the various chassis which make up the equipment.

h. Accessories.- Circuit schematics of the plug-in oscillator unit and plug-in output unit are shown in figures 52 and 53. The crystal controlled oscillator employs a circuit which is conventional for crystals in this frequency range. Plate supply for the oscillator is obtained through pin 2 on the octal socket. The 6C4 triode simply replaces the keyed buffer triode section of V-721, which was not involved in the QHB oscillator circuit proper, to keep the QHB circuit as nearly normal as possible. The plug-in oscillator generates almost as much signal voltage as the original QHB oscillator, and should have no effect on the output power of the QHB transmitter. The frequency stability of this oscillator, determined by the crystal characteristics, is such that over the temperature range 0° C to 50° C the frequency should remain within ± 0.005% of its nominal frequency (which is 65.000kc ± 1 cycle at 25° C).

The plug-in output unit, figure 53, does not alter the QHB receiver circuit since the 6SG7 circuit is not changed, but provides a cathode follower output stage to feed the 65-kc i-f signal into the transmission line. The cathode follower is necessary to prevent the transmission line from loading or altering the characteristics of the QHB i-f circuit. The transmission line serves the dual purpose of supplying the 6C4 cathode follower with plate voltage as well as carrying signal to the Doppler-Range Rate Correlator, giving rise to the circuit arrangement shown in figure 53.

SECTION D
CONCLUSIONS

11. The Doppler-Range Rate Correlator (DRRC) has been bench tested and demonstrated with simulated QHB targets in a background of white noise. Although these tests are by no means conclusive, simulated echos were detected on the DRRC display, after a five-ping integration period, which were very difficult to recognize by ear alone at the QHB audio output.

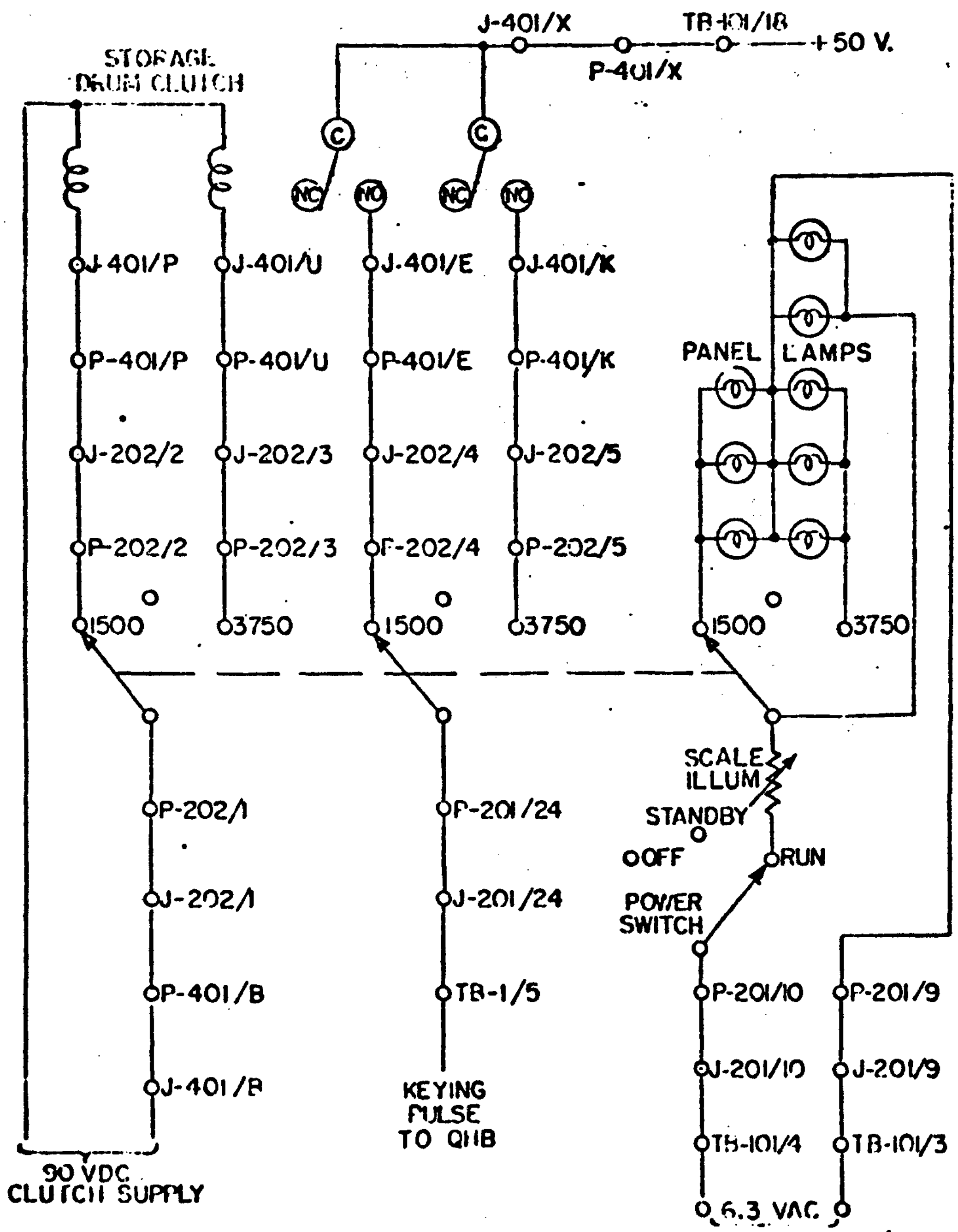


Figure 47. Range Switch, DRRC

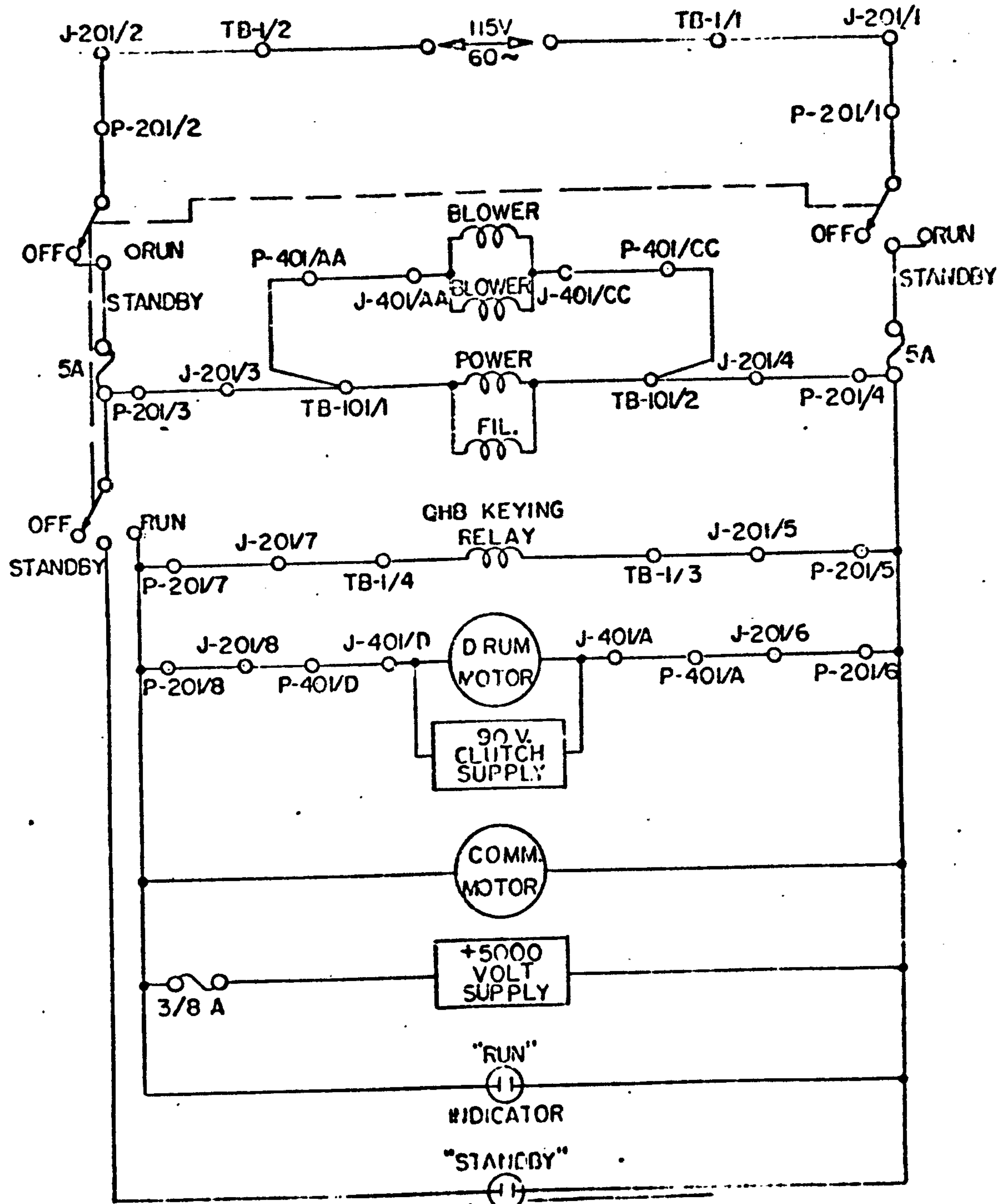


Figure 48. Primary Power Distribution, DRRC

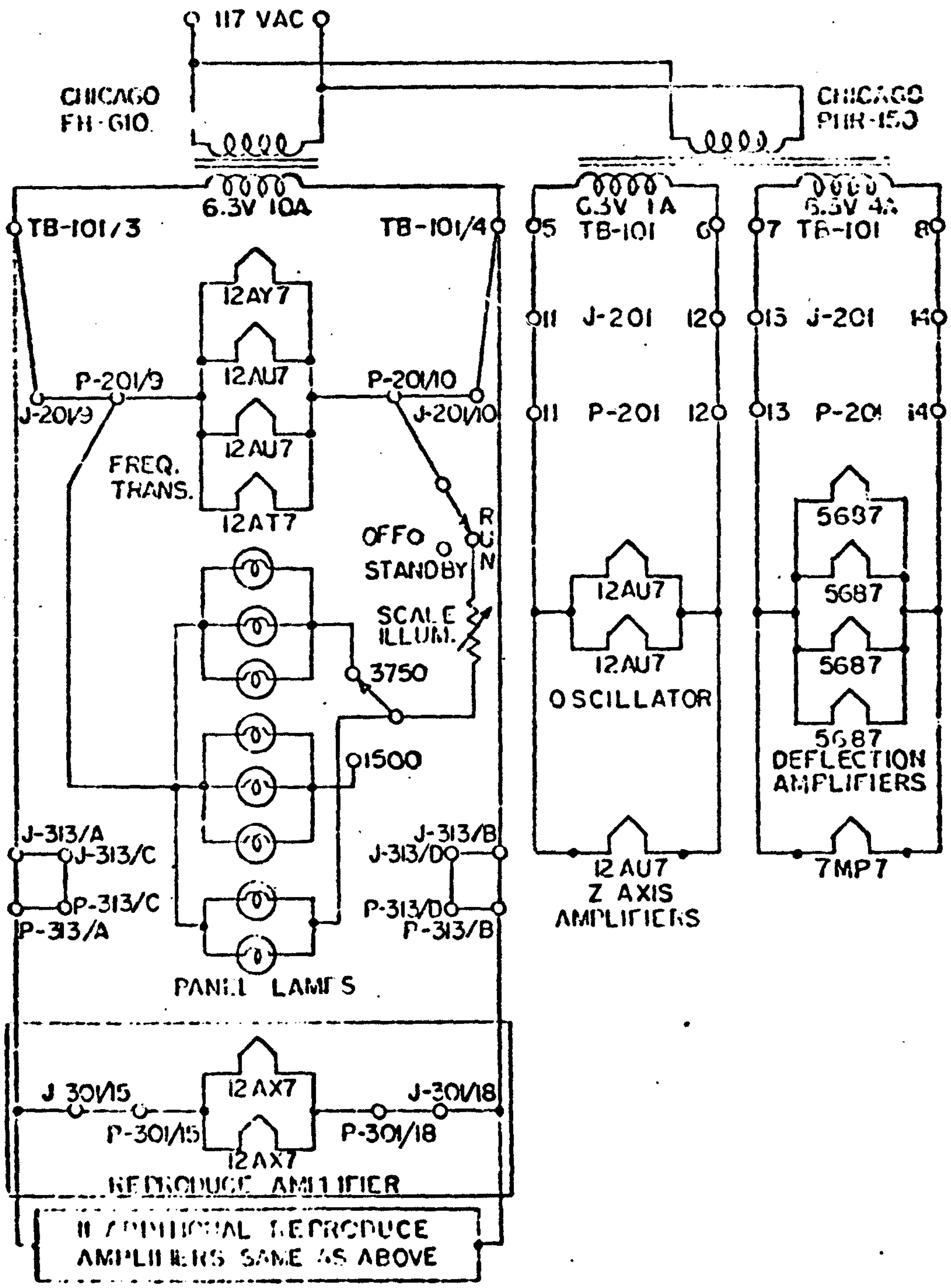


Figure 49. 6.3 VAC Distribution, DRRC

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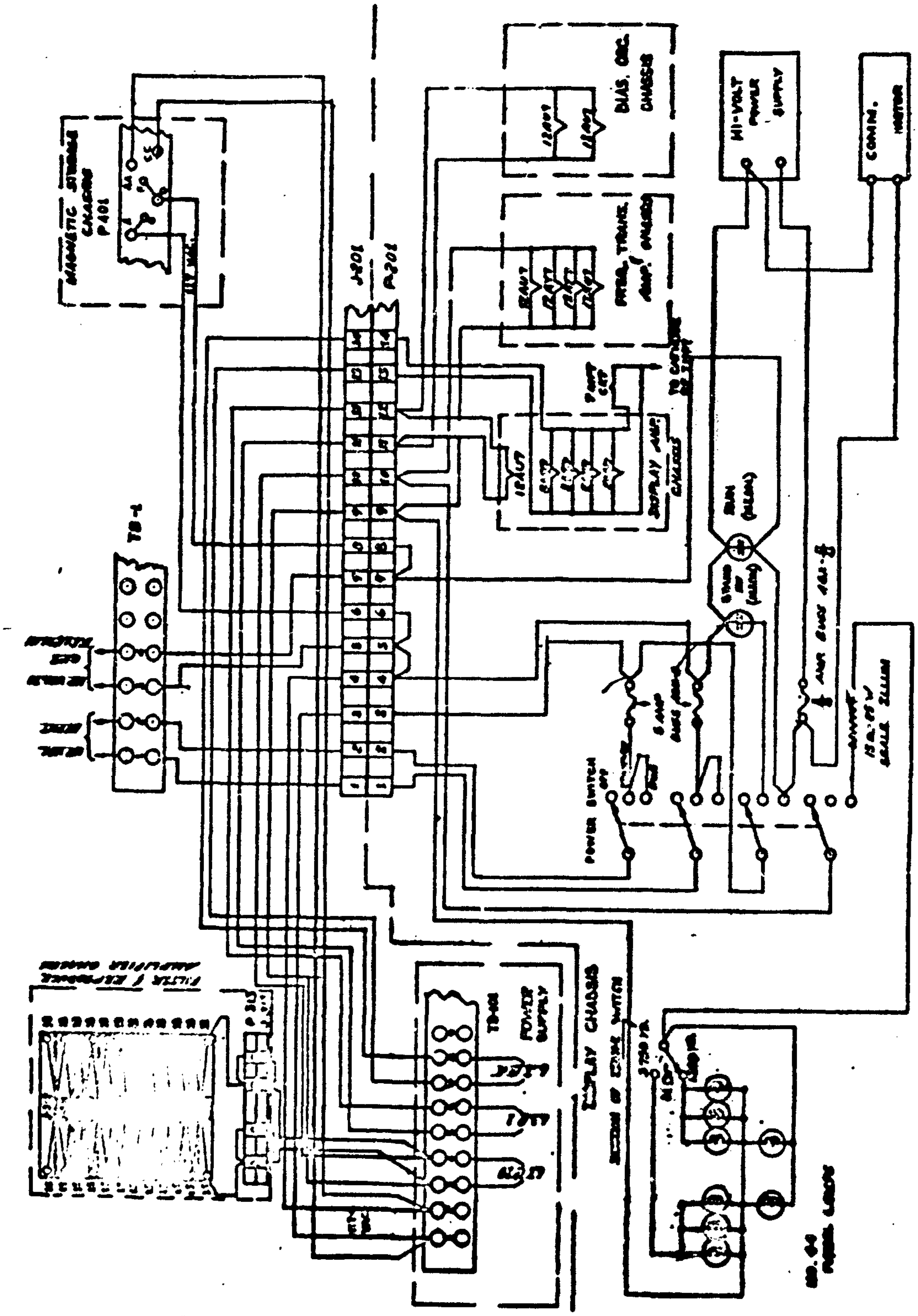

Figure 50. Filament and Primary Power Distribution Diagram, BRRC

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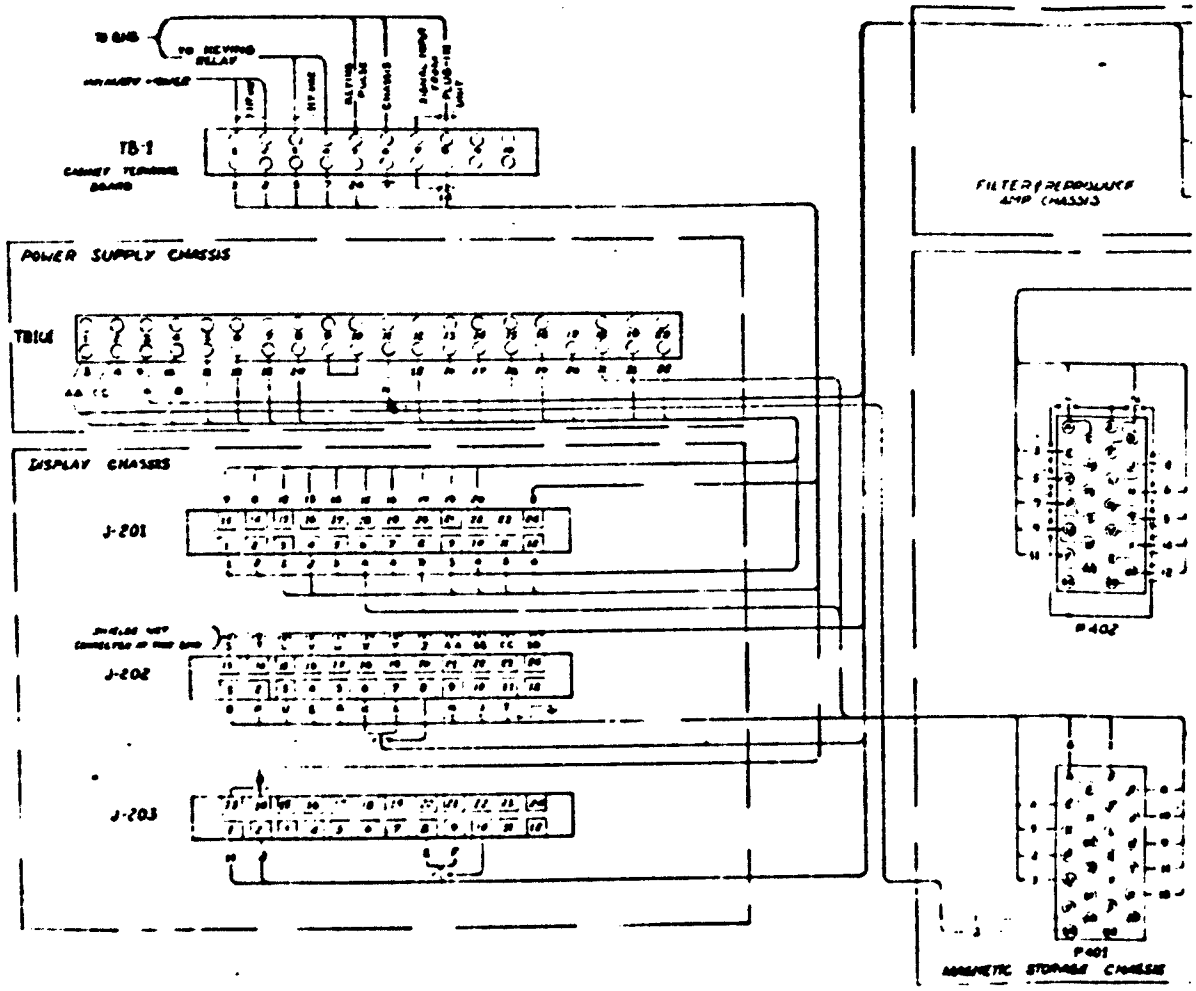

Figure 51. Coplot

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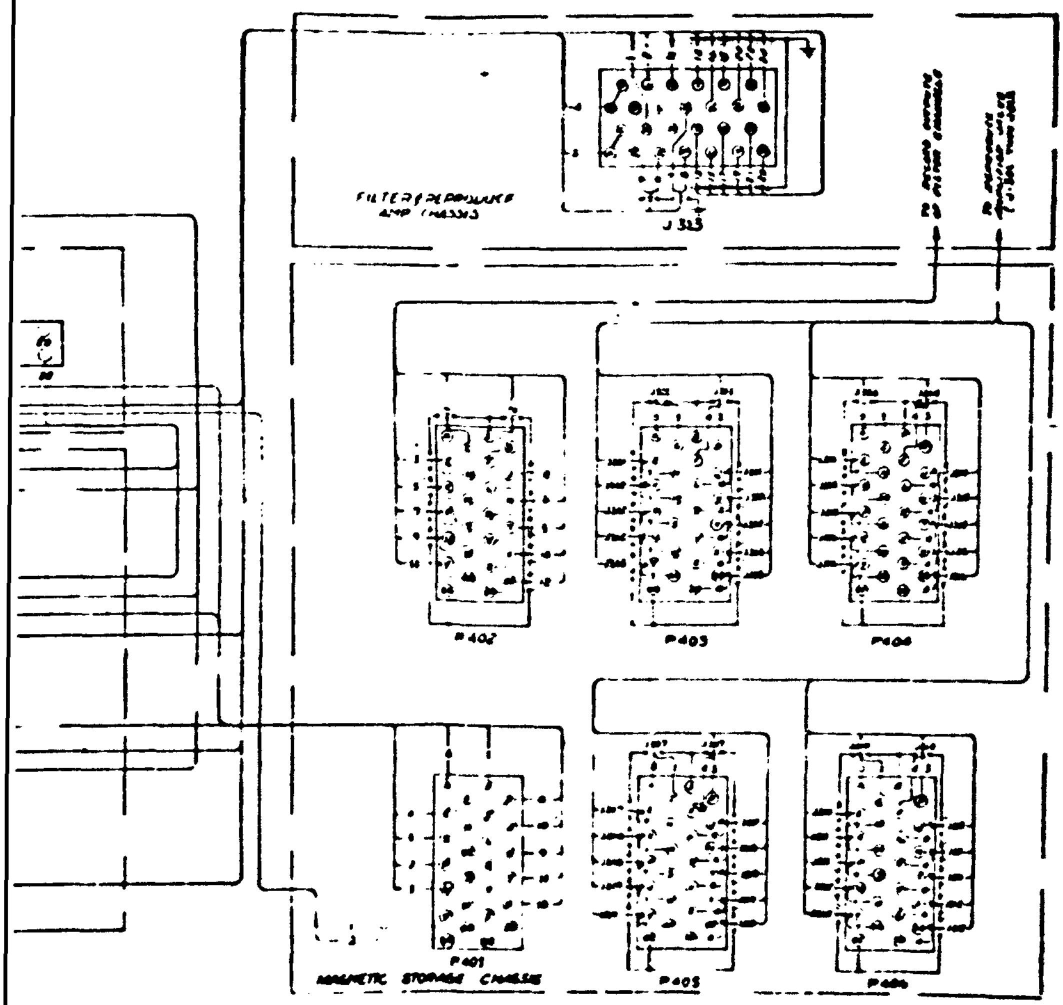

Figure 51. Coplete Interconnection Wiring Diagram, DRRC

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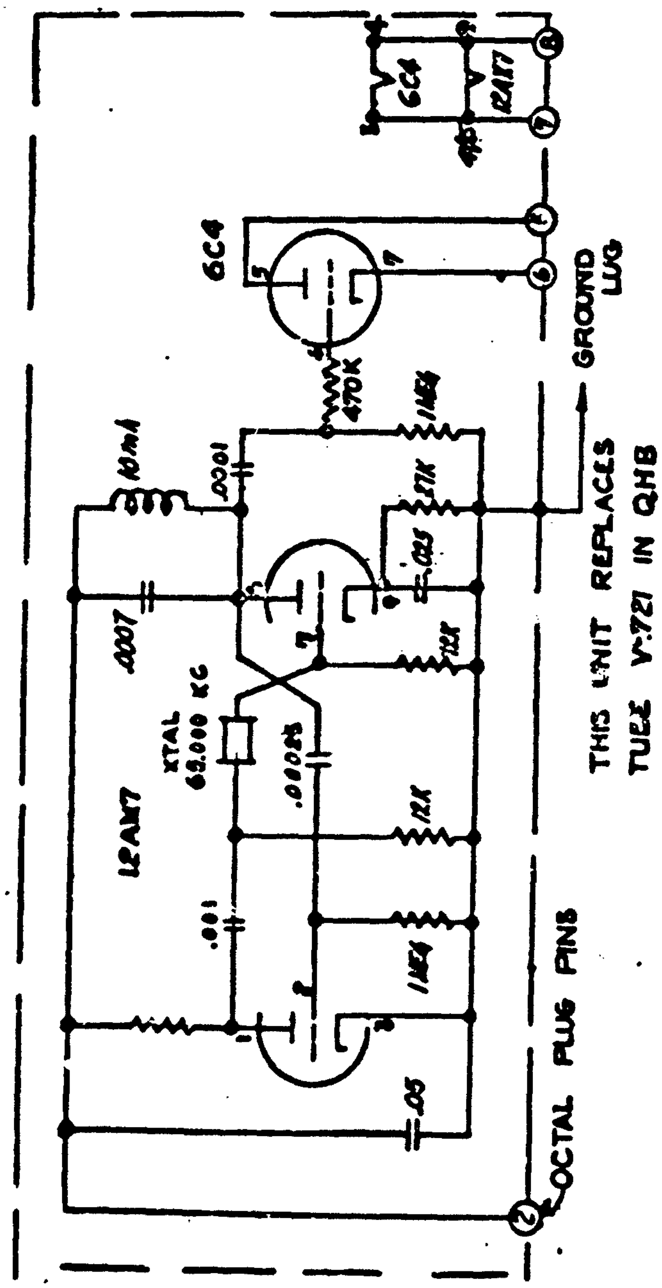

Fig[illegible]0. Schematic Diagram, Plug-in Oscillator Unit, DRRC

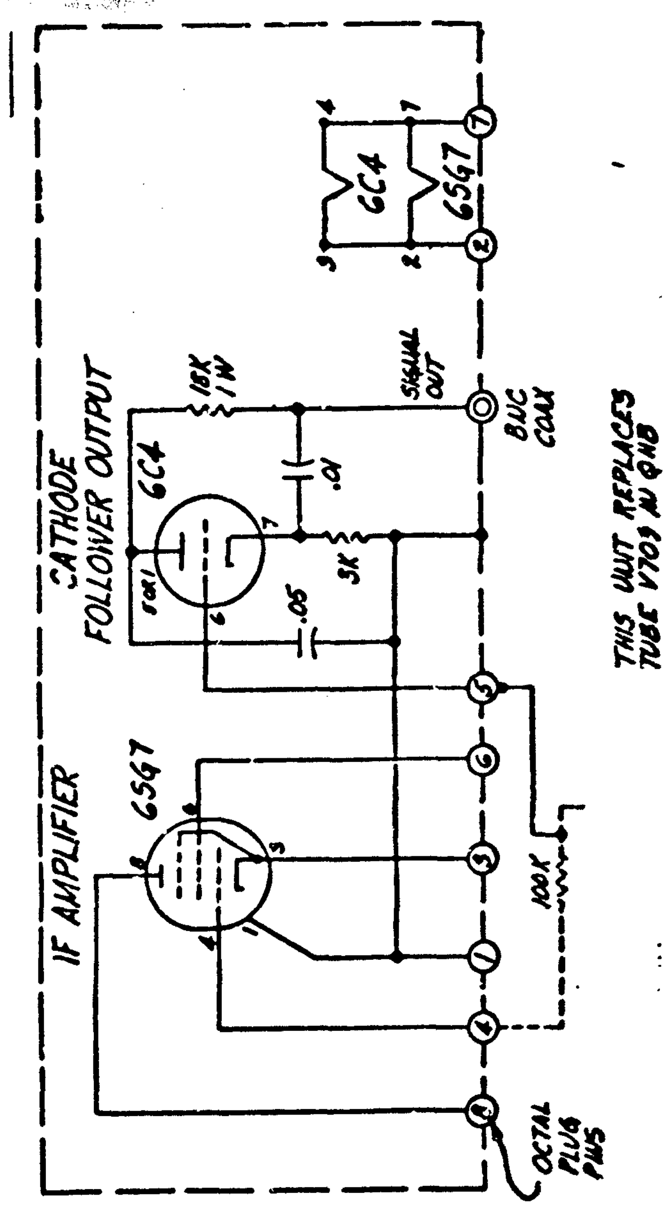

Figure 53. Schematic Diagram, Plug-in Output Unit, DRRC

[redacted]

The tests conclusively demonstrated a marked improvement in echo to background ratio due to the integration over a five-ping interval. Although the lack of reverberations and substitution of white noise for water noise would make it difficult to extrapolate the results of the simulated tests to forecast performance under actual operating conditions, the results of the simulated tests are promising enough to warrant sea trials of this equipment to assess its performance.

PART II
RECOMMENDATIONS

12. A demonstration model of the Doppler-Range Correlator has been developed and bench tested. and simulated performance has been successfully demonstrated. In view of the fact that actual performance can only be assessed under operational conditions aboard ship with real water noise, reverberation, and targets, it is highly desirable that an engineering test at sea be conducted. It is recommended that this contract be amended to include such a sea test and subsequent reports of the results. It is suggested that the results of the sea trials be appended to this report as an addendum.

Prepared by T. E. Bayston
T. E. Bayston
Sr. Engineer

Approved by T. F. Burke
T. F. Burke
Section Head

H. M. Williams
H. M. Williams
Project Engineer

C. B. Rayback
C. B. Rayback
Chief Engineer